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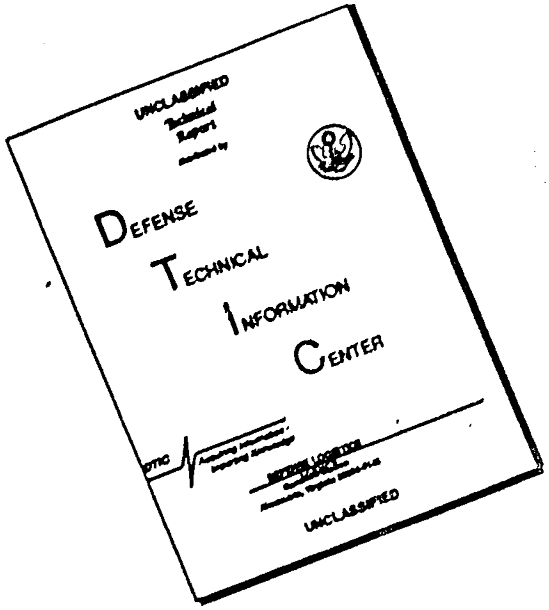

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A LIMITED STUDY OF EFFECTS OF MIXED TRAFFIC ON FLEXIBLE PAVEMENTS

TECHNICAL REPORT NO. 3-587

January 1962

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

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1 Incl
A Limited Study of Effects of Mixed Traffic on Flexible Pavements Technical Report No. 3-587, January 1962 (8 Cys)

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ARMY-MRC VICKSBURG, MISS

PREFACE

The investigation reported herein is a part of the project authorized by the Office, Chief of Engineers, in "Instructions and Outline for Design Criteria for Army Airfields and Heliports (FY 1959)," dated May 1958. The investigation was conducted by the Flexible Pavement Branch, Soils Division, U. S. Army Engineer Waterways Experiment Station, for the Civil Engineering Branch, Engineering Division, Military Construction, Office, Chief of Engineers. Professors Arthur Casagrande, R. B. Peck, R. E. Fadum, and K. B. Woods, and Mr. O. J. Porter were consultants for this study. Engineers of the Waterways Experiment Station actively engaged in directing and conducting this investigation were Messrs. W. J. Turnbull, C. R. Foster (formerly with the Waterways Experiment Station), A. A. Maxwell, R. G. Ahlvin, and Donald N. Brown. Mr. Brown reviewed the test data and prepared this report.

Col. A. P. Rollins, Jr., CE, Col. Edmund H. Lang, CE, and Col. Alex G. Sutton, Jr., CE, were Directors of the Waterways Experiment Station during the course of this investigation and preparation of this report. Mr. J. B. Tiffany was Technical Director.

CONTENTS

SUMMARY

Traffic was applied to a flexible pavement test section, consisting of a well-graded limestone base course constructed on a weak clay subgrade, with 10,000-, 25,000-, and 50,000-lb single-wheel-load test carts to study the effects of mixed traffic on flexible pavements not subject to frost conditions or other conditions requiring special consideration. Deflection, deformation, density, and CBR were measured at specified intervals of test traffic.

In general the test results indicated that: (a) the life of a flexible pavement may be reduced by as much as 67% when as little as 2% of the traffic results from wheel loads two and one-half times larger than the design load; (b) flexible pavements will not necessarily fail immediately when subjected to overload traffic up to five times larger than the design load; (c) the rate of failure of flexible pavements subjected to overload traffic depends upon the amount and magnitude of this traffic, total thickness of pavement structure, and the condition of the pavement and base course; and (d) current criteria for thickness design of a flexible pavement structure are conservative for light loads. Specific test results are summarized as follows.

Deflection and Deformation

The amount of deflection or deformation decreased with increased base course thickness and increased with increase in wheel load or repetitions of traffic.

The rate of increase of the amount of deflection or deformation with repetitions of test traffic increased with increased wheel load and decreased with increased base course thickness.

Areas of the test section which eventually failed under the test traffic showed a deflection of at least 0.25 in. and deformed at least 0.30 in. prior to 100 applications of traffic.

Base Course Density and CBR

The average base course density was at least 100% of modified AASHO

density in all areas of the test section at the start of traffic testing, and the density never became less than 94% of modified AASHO density, even after complete failure of a particular area at the test section.

The base course CBR varied from 85 in section I to 153 in section III at the start of traffic testing and was reduced to at least 60 prior to completion of 100 applications of traffic in all areas which eventually failed under traffic.

Coverages Versus Percentage of Design Thickness

In the specific cases where data were obtained, the amount of traffic which caused failure was four times larger than that which was expected to cause failure according to existing criteria.

Equivalent Traffic

The number of passes of the basic load equivalent to one pass of overload traffic for several conditions is shown below:

		Equivalent Traffic Passes	
Section	Failure Condition	10,000-lb Single-Wheel Load	25,000-lb Single-Wheel Load
I	First indication	53	1
I	Complete	106	1
II	First indication	371	1

Effects of Overload Traffic

In section I, lane A, which was subjected to basic traffic only, had a test life over three times the test life of lanes B and C which were subjected to mixed traffic.

In section II, lane A, which was subjected only to basic traffic, had a test life of at least two and three-fourths times that of lanes B and C which were subjected to mixed traffic.

In section III, lane A, which was subjected to basic traffic only, did not fail or show any indication of failure. Lanes B and C showed an indication of failure after 1000 applications of mixed traffic.

A LIMITED STUDY OF EFFECTS OF MIXED TRAFFIC ON FLEXIBLE PAVEMENTS

PART I: INTRODUCTION

Background, Purpose, and Scope

1. Limited observations of aircraft operations at Army airfields indicate that pavements at practically all of these installations are used occasionally by one or more of the following Air Force cargo-type aircraft, some of which subject the pavements to loads greater than those for which they were designed:

Aircraft Designation	Gear Configuration	Maximum Load on Single Wheel or Twin Wheel of Main Gear, lb
C-47	Single	15,245
C-131	Twin, tricycle	19,770
C-123	Single, tricycle	22,455
C-130	Single tandem	28,100
C-119	Twin, tricycle	32,750
C-54	Twin, tricycle	36,950
C-124	Twin, tricycle	86,550

It obviously would not be economical to design Army airfield pavements for capacity operation of large cargo-type aircraft when these aircraft may use the pavements only occasionally. However, since practically all pavements at Army airfields have been designed for use by aircraft considerably lighter than those listed above, it is essential that criteria be developed by which the effects of mixed traffic (see definition in paragraph 4) on pavements can be predicted.

2. The Corps of Engineers, Department of the Army, has for several years been actively engaged in investigations relative to development of adequate design criteria for Army airfields and heliports. Much of these design criteria can be based on results of research already accomplished in connection with development of design criteria for Air Force airfields. However, the criteria pertaining to the combined effects of various types and weights of aircraft on pavements are not well validated, and are therefore not adequate for predicting these effects. Consequently, the

tests described herein were undertaken to determine the combined effects of various types of aircraft of widely varying weights on flexible pavements of various thicknesses. Frost conditions or other conditions requiring special treatment are not considered in this investigation.

3. The investigation comprised (a) the construction of a flexible pavement test section composed of three sections (I, II, and III as shown in plate 1), each section having a different thickness of base course; (b) subdividing the sections into three traffic lanes (A for basic-load traffic only, and B and C for basic plus overload, or mixed, traffic), and traffic-testing with load carts producing single-wheel loads of 10,000, 25,000, and 50,000 lb. These tests constitute a part of a comprehensive investigation being conducted at the Waterways Experiment Station relative to development of design criteria for Army airfields and heliports.

Definitions of Terms Used in This Report

4. The following terms are defined as specifically used in this report:

Basic load. A 10,000-lb single-wheel load.

Overload. A 25,000- or 50,000-lb single-wheel load.

Basic traffic. Traffic of a 10,000-lb single-wheel load.

Overload traffic. Traffic of a 25,000- or 50,000-lb single-wheel load.

Mixed traffic. Any combination of basic and overload traffic.

Pass. One trip of the test load cart over a particular test lane or section.

Coverage. The actual coverage of every point in a particular test lane or section by a specific wheel load. Several passes are usually required to effect one coverage, the number depending on the size of the load wheel and width of the test lane or section. Traffic applications of the basic load are expressed in terms of coverages. For the size of tire, tire pressure, and width of test lane used in this study, 5.3 passes equal one coverage. Overload traffic is expressed in terms of passes.

Applications of test traffic. A collective term numerically equal to the number of 10,000-lb single-wheel load coverages and used as an expedient to indicate the total amount of test traffic that has been applied to the test section at a particular time instead of writing out a long list of the number of coverages and passes of various single-wheel loads applied to the separate lanes.

> Example: 400 applications of test traffic on the test section would, according to table 1, consist of: 400 coverages of a 10,000-lb single-wheel load on lane A, 400 coverages of a 10,000-lb single-wheel load plus 40 passes of a 25,000-lb single-wheel load on lane B, and 400 coverages of a 10,000-lb single-wheel load plus 36 passes of a 25,000-lb single-wheel load plus 4 passes of a 50,000-lb single-wheel load on lane C. According to the same table, 700 applications of test traffic on the test section would consist of: 700 coverages of basic load on lane A, 700 coverages of basic load plus 70 passes of 25,000-lb single-wheel load on lane B, and 700 coverages of basic load plus 63 passes of a 25,000-lb single-wheel load plus 7 passes of a 50,000-lb single-wheel load on lane C.

First indication of failure. When subgrade shear cracks of the type shown in photograph 9 became visible on the surface of the test section, they were considered the first indication of failure.

Complete failure. When any lane in a section became so deformed that it was difficult to continue application of test traffic, the lane was considered to have failed completely.

Deflection. Total downward vertical displacement, both elastic and permanent, of a point on the surface of the test section resulting from any one application of load at that point.

Deformation. Total permanent vertical displacement of a point on the surface of the test section resulting from all loads applied at that point.

PART II: THE TEST SECTION

Location and Layout

5. The mixed traffic test section was constructed under shelter at the Waterways Experiment Station. The surfaced area of the test section was approximately 35 ft wide and 210 ft long. The actual traffic tests were conducted in an area 12 ft wide and 150 ft long, consisting of three 4-ft-wide lanes, designated A, B, and C, in each of three 50-ft-long sections, designated I, II, and III (see plates 1 and 2).

Subgrade

Material

6. The subgrade was constructed of a fat, gray clay described locally as "Long Lake buckshot clay." This material has a liquid limit of 62, a plasticity index of 37, and is classified as CH according to the Unified Soil Classification System. Gradation of this material is shown in plate 3, and CBR, moisture content, and density curves are shown in plate 4.

Construction

7. The subgrade for the mixed traffic test section was originally constructed for use in another project approximately 13 months prior to its use in this investigation. At that time, the topsoil in the test area was removed to a depth of [illegible] in. The subgrade material was pulverized, water was added until the water content was approximately [illegible] of the dry weight of the soil, and the material was placed in five lifts to achieve a total subgrade thickness of [illegible] in. after compaction. In an effort to produce a CBR of [illegible] in the subgrade, each lift was compacted by first "walking down" with a [illegible] tractor and then applying two coverages of a [illegible] dump truck having a total load of [illegible] lb and a tire pressure of [illegible] psi. Construction-control tests showed that an average CBR of [illegible] and an average dry density of [illegible] lb per cu ft were obtained at an average water content of [illegible]. However, tests conducted immediately before and during application of mixed traffic on the test section in the investigation reported herein showed that an average CBR of [illegible], an average dry density of [illegible] lb per cu ft, and an average water content of [illegible] existed within the subgrade (see table [illegible]). [illegible] heavy clay material at a moisture content well above

optimum and is therefore not sensitive to change in strength, moisture content, or even density as a result of traffic applied. It was therefore decided that an average of test results regardless of status of traffic gives the best representation of test section conditions.

Base Course

Material

8. The base course was constructed of a graded crushed limestone identified locally as "blend No. 2" of Franklin County, Tennessee, crushed limestone. The portion of this material passing the No. 40 sieve has a liquid limit of 16, a plasticity index of 2, and is classified as GW-GM according to the Unified Soil Classification System. Grain-size distribution curves for this material are shown in plate 5, and CBR and modified AASHO compaction characteristics are shown in plate 6.

Construction

9. An area within the limits of the existing subgrade, approximately 32 ft wide and 150 ft long, was excavated to depths equal to the proposed base course thicknesses, 9, 12, and 15 in., shown in fig. b of plate 1. These thicknesses were selected on the basis of the thickness required for capacity operation (5000 coverages) of the basic load which, according to current criteria, is 13 in. Fig. 1 shows the subgrade (section III

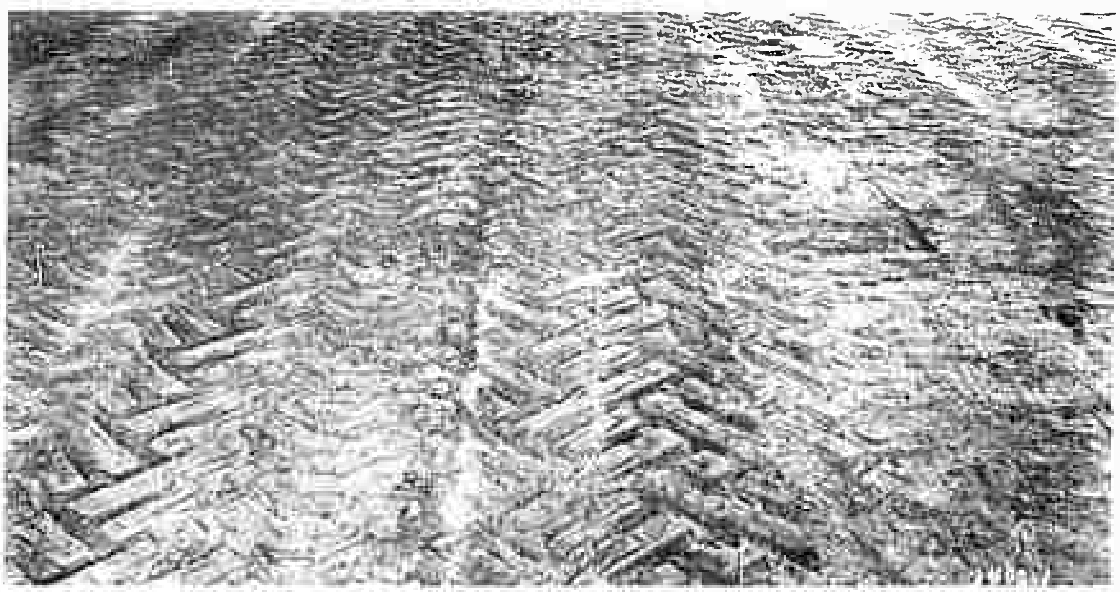

Fig. 1. Subgrade of test section before base course construction

in foreground) just before beginning base course construction.

10. The base course material was processed on a paved area a short distance from the test section site and transported to the site in dump trucks. Processing consisted of thoroughly mixing the material and adding sufficient water to essentially saturate it. Two 3-in. lifts were placed in section III and one 3-in. lift was placed in section II. Uniform thickness of lifts was maintained by spreading the material with a bituminous paving machine as shown in fig. 2. These first lifts of base course

Fig. 2. Bituminous paving machine spreading lifts on base course

material were compacted with 16 passes of a rubber-tired roller loaded to a total weight of 75,000 lb and with tires inflated to 70 psi (fig. 3). An appreciable amount of movement in the subgrade was observed during compaction of the base course.

Fig. 3. Rubber-tired roller used for compacting base course

11. A 4-in. lift of base course material was then placed over the entire test section and compacted with 10 coverages of the 10-ton three-wheel roller shown in fig. 4. In addition, section III was subjected to

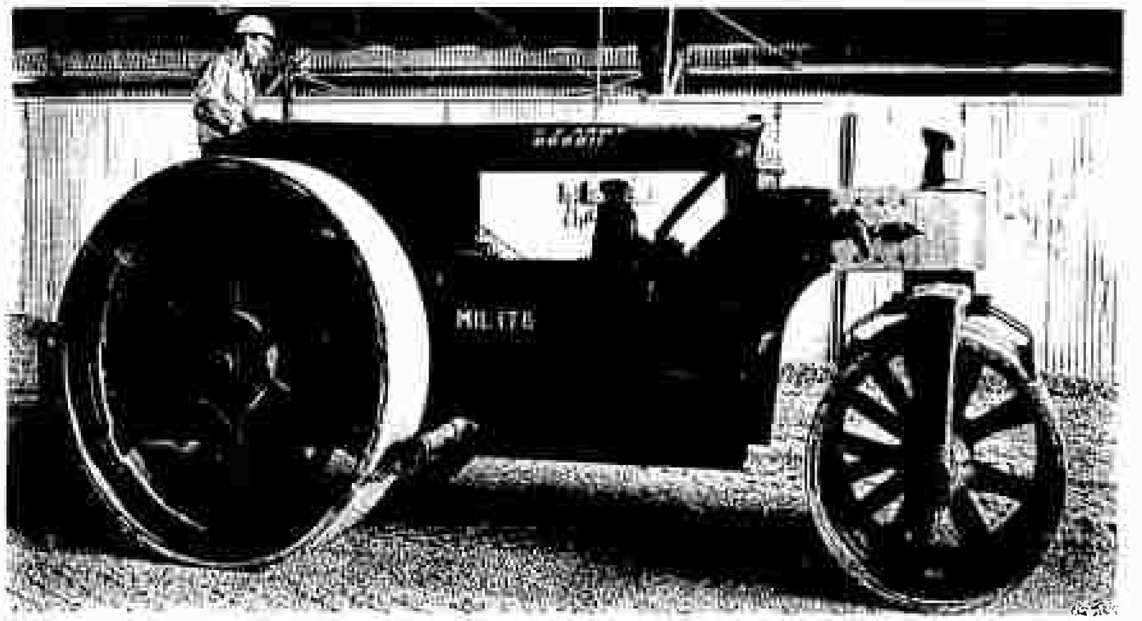

Fig. 4. Ten-ton roller used for compacting base course

10 passes of the 75,000-lb rubber-tired roller. This compaction effort caused an appreciable amount of movement in the clay subgrade in section III. Accordingly, the total load on the rubber-tired roller was reduced to 50,000 lb for compaction of the remainder of the base course. A final 3-in. lift of base course material was placed over the entire test section and compacted with 16 coverages of the 50,000-lb rubber-tired roller in sections I and II and 24 coverages in section III. After this compaction a ditch was opened along the left side of the test section to drain excess water from the base course. The base course was allowed to drain for one week, then 8 passes of the 50,000-lb roller and 10 passes of the 10-ton three-wheel roller were applied to the entire test section. Another week was allowed for further drainage and for the base course to cure. After this period, 8 coverages of the 10-ton three-wheel roller were applied to the entire test section. The completed base course was primed with MC-1 asphalt applied at a rate of 0.25 gal per sq yd at a temperature of 150 F. It was then surfaced with 2-1/2 in. of asphaltic concrete.

12. It was intended that the test section, constructed as described

above, would be subjected to the mixed traffic. However, subsequent events showed that modification of the test section would be necessary.

Modification of Test Section

13. It was anticipated that the test section as constructed would not withstand more than 1000 coverages of the project traffic (in fact, certain portions of the test section were expected to fail after approximately 300 coverages). However, as explained below, traffic tests did not verify this.

14. The test section was subjected to test traffic during the period October-November 1958. The mean monthly temperature during these months was 65.1 F and 58.4 F, respectively. The maximum and minimum temperatures recorded during the days on which traffic was applied to the test section during this period were as follows:

Month	Day	Temperature, Deg F Maximum	Temperature, Deg F Minimum
October	20	79	44
	21	82	47
	29	65	45
	30	66	50
	31	63	52
November	1	54	47
	2	64	37
	3	67	40
	4	68	51
	14	80	58
	15	73	67
	16	77	69
	17	83	69
	18	83	55
	19	54	40
	20	65	33
	21	71	32
	22	75	35
	23	75	41
	24	71	46
	25	75	47
	26	75	52
	27	59	38
	28	58	34

Traffic was applied to the test section until lane A had been subjected to

1000 coverages of a 10,000-lb single-wheel load, lane B to 1000 coverages of a 10,000-lb single-wheel load plus 100 passes of a 25,000-lb single-wheel load, and lane C to 1000 coverages of a 10,000-lb single-wheel load plus 90 passes of a 25,000-lb single-wheel load plus 10 passes of a 50,000-lb single-wheel load.* The test section showed no visible adverse effects from this traffic (see fig. 5). Since failure had been expected after considerably less traffic, it appeared that some change in the traffic test loads or pavement thickness would need to be made if the desired results were to be obtained.

15. A careful study of the known facts relative to construction and testing of the section indicated that the rigidity of the asphaltic concrete surfacing resulting from low air temperature had likely increased the strength of the flexible pavement structure to such an extent that the test traffic was having little adverse effect on the test section. Therefore, the asphaltic concrete plus as little as possible of the base course was stripped off the test section. The exposed base course was then "wet down," recompacted with 16 coverages of the 50,000-lb rubber-tired roller and 10 coverages of the 10-ton three-wheel roller, and refinished with a seal coat. Thicknesses of the base course in sections I, II, and III after removal of the asphaltic concrete and a portion of the base course were 5, 8, and 11 in. as shown in fig. c of plate 1; these thicknesses are 38.5, 61.5, and 84.6%, respectively, of that presently required in design of flexible pavements for capacity operation of a 10,000-lb single-wheel load. The density and CBR of the completed base course varied according to the thickness of base course above the low-strength clay subgrade (see table 4, zero coverage).

16. The mixed traffic tests described subsequently were conducted on the test section modified as described above. Also it is pointed out that all test data analysis, discussion, and conclusions presented in this report are based on results obtained from tests performed on the test section after removal of the asphaltic concrete and a portion of the base course (see fig. c of plate 1).

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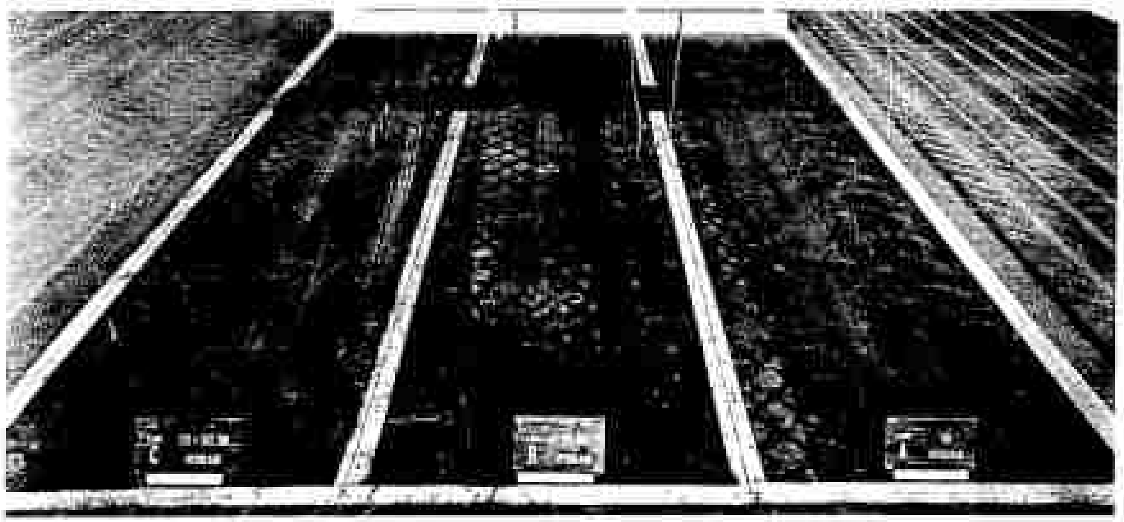
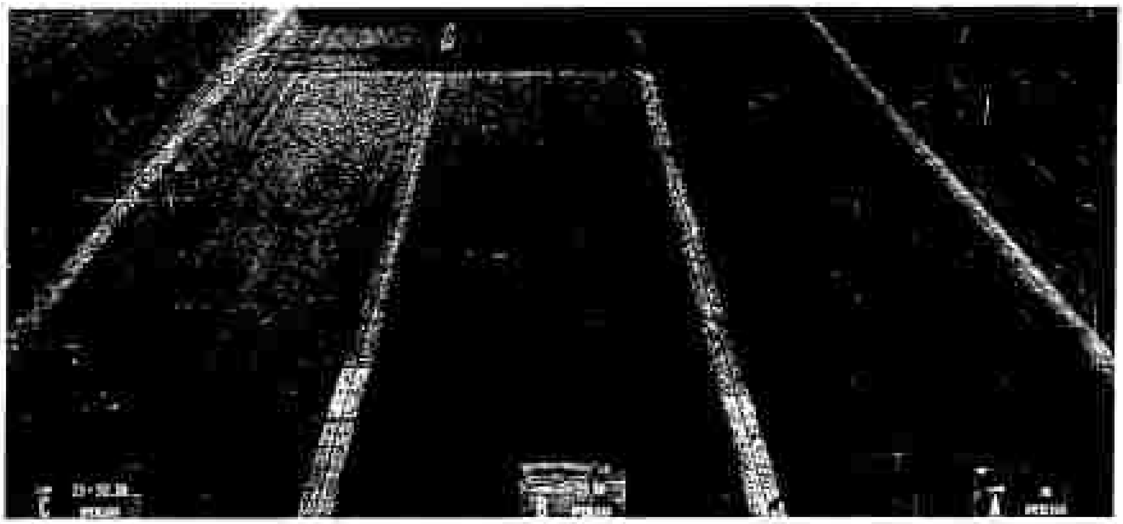
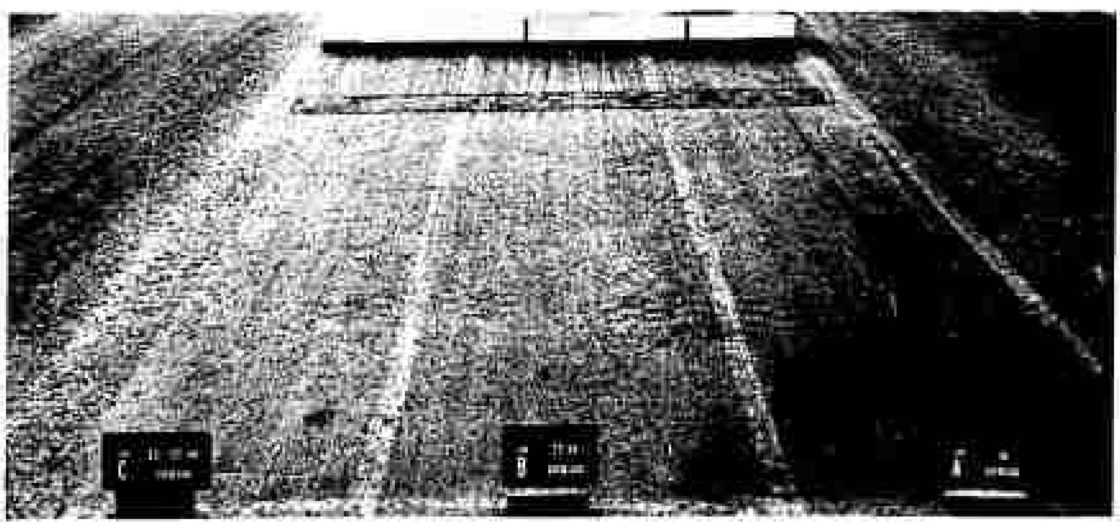
* Selection of these loads and the equipment used in applying them are discussed in paragraphs 17 and 18.



a. Section I



b. Section II



c. Section III

Fig. 5. Test section after 1000 applications of traffic (before removal of 2-1/2-in. asphaltic concrete surface course)

PART III: METHOD OF TEST

Selection of Test Traffic Loads

17. A 10,000-lb single-wheel load was selected as the basic load for the traffic tests reported herein because this wheel load is equal to or larger than the wheel load of the majority of Army aircraft now in use. The 25,000- and 50,000-lb single-wheel loads were selected as generally representative of the wheel loads of the heavy overload traffic being applied on Army airfield pavements by the Air Force cargo-type aircraft listed in paragraph 1.

Load Carts Used to Apply Basic and Overload Traffic

18. Basic data relative to the test carts used to apply traffic to the test section follow.

Single-Wheel Load lb	Tire Type	Tire Size	Inflation Pressure psi	Contact Area sq in.
10,000	I	34-9.9	100	91
25,000	I	56-16	100	232
50,000	III	25.00-28	100	479

Basic traffic was applied to the test section with the 10,000-lb single-wheel load test cart equipped with 34-9.9, type I, aircraft tires inflated to 100 psi. This cart, shown in fig. 6, was fabricated at WES. Overload traffic was applied to the test section with two test load carts of the type shown in fig. 7. These carts were designed and fabricated at WES. One was equipped with a 56-16, type I, aircraft tire (center tire visible in fig. 7) inflated to 100 psi and was loaded in such a manner as to produce a 25,000-lb single-wheel load. The other was equipped with a 25.00-28, type III, aircraft tire inflated to 100 psi and was loaded to produce a 50,000-lb single-wheel load.

Fig. 6. 10,000-lb single-wheel load cart used to apply basic traffic to test section

Fig. 7. One of the two load carts used to apply overload traffic to test section

Sequence of Application of Traffic

19. Limited observations of aircraft operations at Army airfields indicate that approximately 2% of the aircraft operating at these installations are large cargo-type Air Force aircraft and that about one in ten of these aircraft is considerably heavier than any aircraft considered in design of pavements for most Army airfields. It was also observed that operations of these large cargo-type aircraft were fairly well interspersed with the normal operations of Army aircraft. It was decided on the basis of these observations that the test traffic to be applied to the test section in this investigation should be composed of 98% basic traffic and 2% overload traffic, all overload traffic applied to one portion of the test section should be applied with the 25,000-lb single-wheel load test cart, and approximately 90% of the overload traffic applied to another portion of the test section should be applied with the 25,000-lb single-wheel load test cart and 10% with the 50,000-lb single-wheel load test cart. Lane A of the test section was subjected to basic traffic only, lane B to basic traffic and overload traffic applied with the 25,000-lb single-wheel load cart, and lane C to basic traffic and overload traffic applied with the 25,000- and 50,000-lb single-wheel load carts. The sequence of application of traffic developed as a guide for application of traffic to the mixed traffic test section is shown in table 1.

Types of Data Obtained

20. The following test data were obtained at specified intervals of traffic (as indicated in table 1), at the first indication of failure, and after complete failure of a particular area of the test section as determined by visual observation of the effects of traffic on the test section.

a. Complete test data. Complete test data included:

(1) Cross sections at 10-ft intervals along the entire length of the test section.

(2) Deflection and deformation measurements in each section and lane for each load cart in use at time of test.

(3) In-place soil tests, including CBR, density, and water

content, in the subgrade and base course in each lane of each section.

b. Partial test data. Partial test data consisted of determining the elevation of each of 36 locations in the test section (see plate 2) at specified intervals of test traffic (table 1).

Photographs of the effects of traffic at certain stages in the traffic tests were also made.

Test Procedure

21. After modification of the test section as described in paragraph 15 was completed, the area designated for traffic testing was laid out and marked (see plates 1 and 2). Lines were marked along each side of the test section and at the ends of lanes B and C for guidance in application of traffic to the test section (see photograph 1). The numbers 2, 1, and 3 in the immediate foreground of photograph 1 indicate the points at which and the order in which passes of overload traffic were applied to lanes B and C. Traffic was applied in accordance with the sequence of application of traffic shown in table 1. Complete and partial test data were obtained at intervals as indicated in table 1. In areas where complete failure occurred, the failed area was rough-graded, brought back to grade with a layer of base course material and a 3-in. layer of sand, and covered with landing mat; then test traffic was continued. A total of 1700 applications of traffic were applied. After 1000 applications of traffic, lane A of section II and all of section III of the test section remained in service. The last 700 applications had practically no visible effect on these areas of the test pavement. Consequently, it was concluded that further application of traffic was not economically justified in view of the anticipated results, and traffic was stopped after 1700 applications.

PART IV: TEST RESULTS

22. Surface deflection, surface deformation, and in-place soil data determined before and during the traffic tests are shown in tables 2, 3, and 4, respectively. Traffic test results are summarized in table 5 and shown graphically in plates 7-15. Condition of section I at various intervals is shown in photographs 1-6, of section II in photographs 7-15, and of section III in photographs 16-18.

Surface Deflection

23. Maximum deflections measured at specific intervals of test traffic (table 2, plates 7-9) showed generally that:

a. The amount of deflection decreased with increased base course thickness and increased with increase in wheel load or repetitions of traffic.

b. The rate of increase of amount of deflection with repetitions of test traffic increased with increased wheel load and decreased with increased base course thickness.

c. Areas of the test section that eventually failed under the test traffic showed deflections of at least 0.25 in. before 100 applications of traffic.

Surface Deformation

24. Maximum deformations measured at specific intervals of test traffic (table 3, plates 10-12) showed generally that:

a. The amount of deformation decreased with increased base course thickness and increased with increased wheel loads or repetitions of test traffic.

b. The rate of increase of deformations with repetitions of test traffic increased with increased wheel load and decreased with increased base course thickness.

c. Areas of the test section that eventually failed under the test traffic had deformed at least 0.3 in. before 100 applications of test traffic.

Base Course Density and CBR

25. Average values of base course density and CBR determined at

selected intervals of test traffic (table 4, plates 13-15) showed generally that:

a. The average base course density was at least 100% of modified AASHO density in all areas of the test section at the start of traffic testing, and the density never became less than 94% of modified AASHO density even after complete failure of a particular area of the test section.

b. The base course CBR varied from 85 in section I to 153 in section III at the start of traffic testing, and was reduced to 60 by completion of 100 applications of traffic in all areas that eventually failed under traffic.

Coverages Versus Percentage of Design Thickness

26. A coverages versus percentage of design thickness curve, labeled "existing" curve, is shown in plate 16. This curve was developed from test data obtained during numerous investigations made in connection with development of design criteria for pavements to be utilized by Air Force aircraft. It is a general, only poorly validated curve representative of single- and multiple-wheel gear aircraft with loadings varying between 5000- and 200,000-lb single-wheel loads and between 20,000- and 50,000-lb dual-assembly loads. This curve has been used for some 10 or 12 years in the preparation of thickness design curves for pavements to be utilized by various specific aircraft. Sufficient data were obtained during the investigation reported herein to plot two points in plate 16 representative of the coverages versus percentage design thickness relations for a 10,000-lb single-wheel load. The curve passing through these points, labeled "mixed traffic test section curve" in plate 16, is parallel to the existing curve. Comparison of these curves indicates that the relation between coverages and percentage of design thickness may vary considerably with variation in wheel loads, and that design criteria based on the existing curve will be conservative for light wheel loads. In this specific case where test data were obtained, the amount of test traffic which caused the first indication of failure was four times more than that which was expected to cause failure according to the existing curve. For instance, lane A in section I (thickness above subgrade = 5 in. = 38.5% of the design thickness for a 10,000-lb single-wheel load and a 6-CBR subgrade) showed first

indication of failure after 40 coverages of the 10,000-lb single-wheel load (see table 5), but according to the existing curve, lane A in section I should have failed at about 10 coverages of the 10,000-lb single-wheel load. This difference in coverages represents a 35% difference in base course thickness for a 10,000-lb single-wheel load (i.e. the thickness above the subgrade could have been 35% less and this particular pavement still could have withstood 10 coverages of the 10,000-lb single-wheel load).

Test Results in Terms of Equivalent Traffic

Overload traffic

27. The test data obtained during this investigation relative to visual observations, deflection, deformation, and base course density and CBR show, as expected, that traffic of a 50,000-lb single-wheel load is considerably more destructive than that of a 25,000-lb single-wheel load. It is, therefore, logical to expect that overload resulting from operation of 50,000- and 25,000-lb single-wheel loads in combination would be more destructive than that resulting from operation of the 25,000-lb single-wheel load alone. However, the test data relative to operations causing the first indication of failure or complete failure show no difference in overload damage produced by the 25,000-lb single-wheel load alone or in combination with the 50,000-lb single-wheel load. It would seem reasonable to conclude that the overload traffic applied with the 50,000-lb single-wheel load in lane C was too small a percentage of the total overload traffic applied in this lane to produce effects materially different from those resulting from overload traffic applied with the 25,000-lb single-wheel load in lane B.

Basic traffic

28. An example of the computations required to determine the number of passes of basic traffic that is equivalent to one pass of overload traffic follows. This example is for the first indication of failure in section I. Table 5 shows that 40 applications of test traffic in lane A and 20 applications of test traffic in lanes B and C caused the first indication of failure in these lanes. Since all lanes in section I were of equal thickness, it is assumed that the traffic that caused the first indication

of failure in lane A is equivalent to that which caused the first indication of failure in lanes B and C. According to the sequence of application of traffic shown in table 1, 40 applications of test traffic in lane A comprised 40 coverages of the 10,000-lb single-wheel load. Sixteen passes of this test load were required to make one coverage over the entire test section, or 5.3 passes were required for one coverage of each lane. Consequently, 40 coverages of the 10,000-lb single-wheel load comprised 212 (i.e. 40 × 5.3) passes of this test load. Also, according to the sequence of application of traffic shown in table 1, 20 applications of test traffic in lanes B and C comprised 20 coverages of the 10,000-lb single-wheel load plus 2 passes of the 25,000-lb single-wheel load, which in turn are equal to 106 (20 × 5.3) passes of the 10,000-lb single-wheel load plus 2 passes of the 25,000-lb single-wheel load; therefore, let

$$X = 1 \text{ pass of the 10,000-lb single-wheel load}$$

$$Y = 1 \text{ pass of the 25,000-lb single-wheel load}$$

then

$$212X = 106X + 2Y$$

$$212X - 106X = 2Y$$

$$2Y = 106X$$

$$Y = 53X$$

That is, 1 pass of the 25,000-lb single-wheel load is equivalent to 53 passes of the 10,000-lb single-wheel load in section I at the first indication of failure. This value and other values obtained in a similar manner are tabulated below.

		Equivalent Traffic Passes*	
Section	Failure Condition	10,000-lb Single-Wheel Load	25,000-lb Single-Wheel Load
I	First indication	53	1
I	Complete	106	1
II	First indication	371	1

* Sufficient data were not obtained to determine relation for 50,000-lb single-wheel load (see paragraph 27).

These data are not a sufficient basis from which to draw any positive conclusions; however, generally the number of passes of a specific load that is equivalent to one pass of a heavier load varies with thickness and condition of the pavement structure at time of comparison and becomes progressively larger as failure is approached.

Effects of Overload Traffic on Sections I, II, and III

29. Overload traffic on sections I, II, and III of the test section produced the following effects:

a. Section I. Lane A, which was subjected to only basic traffic, had a test life of over three times the test life of lanes B and C which were subjected to mixed traffic.

b. Section II. Lane A, which was subjected to only basic traffic, did not fail under the applied test traffic. Lanes B and C both failed after 630 applications of mixed traffic. Lane A had a test life of at least two and three-fourths times that of lanes B and C.

c. Section III. Lane A, which was subjected to only basic traffic, showed no indication of failure under the applied test traffic. Lanes B and C showed an indication of failure after 1000 applications of mixed traffic.

PART V: CONCLUSIONS

30. On the basis of the test results reported herein, the following conclusions appear justified:

a. Primary conclusions.

(1) The life of a flexible pavement may be reduced as much as 67% when as little as 2% of the traffic results from wheel loads two and one-half times larger than the design load.

(2) Flexible pavements will not necessarily fail immediately when subjected to overloads up to five times larger than the design load.

(3) The rate of failure of flexible pavements subjected to overload traffic will depend upon the amount and magnitude of that traffic, total thickness of pavement structure, and condition of pavement and base course.

(4) The number of passes of basic traffic that is equivalent to one pass of a given overload traffic depends upon the thickness and condition of the pavement and base.

(5) Current criteria relative to pavement structure thickness design are conservative for light loads.

b. Secondary conclusions.

(1) A steady increase of deflection or deformation with repetitions of traffic indicates approaching failure.

(2) A steady decrease in base course CBR with repetitions of traffic indicates approaching failure.

(3) Any reduction in base course density with repetitions of traffic indicates approaching failure.

(4) A steady decrease or leveling out of deflection with repetitions of traffic indicates a stable pavement.

(5) Base course density should be at least 100% of modified AASHO density.

Table 1

Sequence of Application of Test Traffic and Traffic Intervals at Which Test Data Were Obtained*

Lane A: Cov of a 10-kip Single-Wheel Load**	Lane B: Cov of a 10-kip Single-Wheel Load** + Passes of a 25-kip Single-Wheel Load	Lane C: Cov of a 10-kip Single-Wheel Load** + Passes of a 25-kip Single-Wheel Load + Passes of a 50-kip Single-Wheel Load	Test Data†
0	0	0	Complete test data
10	10 + 0	10 + 0 + 0	Partial test data
	10 + 1	10 + 1 + 0	Partial test data
20	20 + 1	20 + 1 + 0	Partial test data
	20 + 2	20 + 2 + 0	Partial test data
30	30 + 2	30 + 2 + 0	Partial test data
	30 + 3	30 + 3 + 0	Partial test data
40	40 + 3	40 + 3 + 0	Partial test data
	40 + 4	40 + 4 + 0	Complete test data
50	50 + 4	50 + 4 + 0	Partial test data
	50 + 5	50 + 5 + 0	Partial test data and deflection measurements in lane C, section I
60	60 + 5	60 + 5 + 0	Partial test data
	60 + 6	60 + 6 + 0	Partial test data
70	70 + 6	70 + 6 + 0	Partial test data
	70 + 7	70 + 7 + 0	Partial test data
80	80 + 7	80 + 7 + 0	Partial test data
	80 + 8	80 + 8 + 0	Partial test data
90	90 + 8	90 + 8 + 0	Partial test data
	90 + 9	90 + 9 + 0	Partial test data
100	100 + 9	100 + 9 + 0	Partial test data
	100 + 10	100 + 9 + 1	Partial test data
110	110 + 10	110 + 9 + 1	Partial test data
	110 + 11	110 + 10 + 1	Partial test data
120	120 + 11	120 + 10 + 1	Partial test data
	120 + 12	120 + 11 + 1	Partial test data
130	130 + 12	130 + 11 + 1	Partial test data
	130 + 13	130 + 12 + 1	Partial test data
140	140 + 13	140 + 12 + 1	Partial test data
	140 + 14	140 + 13 + 1	Partial test data
150	150 + 14	150 + 13 + 1	Partial test data
	150 + 15	150 + 14 + 1	Partial test data

(Continued)

* Traffic applications in lanes B and C are expressed in terms of coverages of basic load plus passes of overload.

** One coverage of the basic load equals 5.[illegible] passes.

† See paragraph [illegible] for list of tests included under "complete test data" and "partial test data."

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Table 1 (Concluded)

Lane A Cov of a 10-kip Single-Wheel Load	Lane B Cov of a 10-kip Single-Wheel Load + Passes of a 25-kip Single-Wheel Load	Lane C Cov of a 10-kip Single-Wheel Load + Passes of a 25-kip Single-Wheel Load + Passes of a 50-kip Single-Wheel Load	Test Data
160	160 + 15	160 + 14 + 1	Partial test data
	160 + 16	160 + 15 + 1	Partial test data
170	170 + 16	170 + 15 + 1	Partial test data
	170 + 17	170 + 16 + 1	Partial test data
180	180 + 17	180 + 16 + 1	Partial test data
	180 + 18	180 + 17 + 1	Partial test data
190	190 + 18	190 + 17 + 1	Partial test data
	190 + 19	190 + 18 + 1	Partial test data
200	200 + 19	200 + 18 + 1	Partial test data
	200 + 20	200 + 18 + 2	Complete test data
300	300 + 29	300 + 27 + 2	Partial test data
	300 + 30	300 + 27 + 3	Partial test data
400	400 + 39	400 + 36 + 3	Partial test data
	400 + 40	400 + 36 + 4	Partial test data
500	500 + 49	500 + 45 + 4	Partial test data
	500 + 50	500 + 45 + 5	Partial test data
600	600 + 59	600 + 54 + 5	Partial test data
	600 + 60	600 + 54 + 6	Partial test data
700	700 + 69	700 + 63 + 6	Partial test data
	700 + 70	700 + 63 + 7	Partial test data
800	800 + 79	800 + 72 + 7	Partial test data
	800 + 80	800 + 72 + 8	Partial test data
900	900 + 89	900 + 81 + 8	Partial test data
	900 + 90	900 + 81 + 9	Partial test data
1000	1000 + 99	1000 + 90 + 9	Complete test data
	1000 + 100	1000 + 90 + 10	Partial test data
1100	1100 + 109	1100 + 99 + 10	Partial test data
	1100 + 110	1100 + 99 + 11	Partial test data
1200	1200 + 119	1200 + 108 + 11	Partial test data
	1200 + 120	1200 + 108 + 12	Partial test data
1300	1300 + 129	1300 + 117 + 12	Partial test data
	1300 + 130	1300 + 117 + 13	Partial test data
1400	1400 + 139	1400 + 126 + 13	Partial test data
	1400 + 140	1400 + 126 + 14	Partial test data
1500	1500 + 149	1500 + 135 + 14	Partial test data
	1500 + 150	1500 + 135 + 15	Partial test data
1600	1600 + 159	1600 + 144 + 15	Partial test data
	1600 + 160	1600 + 144 + 16	Partial test data
1700	1700 + 169	1700 + 153 + 16	Partial test data
	1700 + 170	1700 + 153 + 17	Complete test data

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Table 2

Deflection Before and During Traffic Tests

Section No.	Applications of Test Traffic	Maximum Deflection, in. — Test Load Cart — Lane A 10 kips	Lane B 10 kips	Lane B 25 kips	Lane C 10 kips	Lane C 25 kips	Lane C 50 kips
I	0	0.098	0.140	---	0.200	---	---
	10	---	---	0.390	---	0.410	---
	40	0.198	0.260	0.430	0.280	0.500	---
	50	---	---	0.470	---	---	0.820
	100	0.250	---	---	---	---	---
	160	0.280	---	---	---	---	---
II	0	0.120	0.130	---	0.160	---	---
	10	---	---	0.318	---	0.430	---
	40	0.185	0.240	0.320	0.210	0.440	---
	100	0.210	0.240	0.450	0.242	---	0.470
	200	0.235	0.255	0.480	0.253	---	0.500
	630	---	---	---	---	---	---
	1000	0.240	---	---	---	---	---
	1700	---	---	---	---	---	---
III	0	0.080	0.078	---	0.090	---	---
	10	---	---	0.190	---	0.200	---
	40	0.085	0.078	0.240	0.078	0.215	---
	100	0.085	0.115	0.250	0.140	---	0.260
	200	0.100	0.115	0.260	0.130	---	0.300
	1000	0.120	0.120	0.280	0.120	---	0.310
	1700	0.120	0.120	0.280	0.120	---	0.310

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Table 3

Surface Deformation* During Traffic Tests

Section No.	Lane A: Coverages of 10-kip Wheel Load	Lane A: Pavement Surface Deformation in.	Lane B: Coverages of 10-kip Wheel Load	Lane B: Passes of 25-kip Wheel Load	Lane B: Pavement Surface Deformation in.	Lane C: Coverages of 10-kip Wheel Load	Lane C: Passes of 25-kip Wheel Load	Lane C: Passes of 50-kip Wheel Load	Lane C: Pavement Surface Deformation in.
I	10	0.07	10	1	0.09	10	1	0	0.10
	20	0.09	20	2	0.13	20	2	0	0.16
	40	0.10	40	4	0.24	40	4	0	0.17
	50	0.11	50	5	0.58	50	4	1	0.80
	100	0.50	--	--	--	--	--	0	--
	[illegible]	2.3[illegible]	--	--	--	--	--	0	--
II	10	0.11	10	1	0.09	10	1	0	0.10
	40	0.19	40	4	0.33	40	4	0	0.08
	100	0.21	100	10	0.31	100	9	1	0.31
	200	0.23	200	20	0.40	--	--	--	--
	300	--	--	--	--	300	27	3	0.51
	400	--	400	40	0.52	--	--	--	--
	500	0.18	--	--	--	--	--	--	--
	630	--	630	63	1.20	630	57	6	1.30
	1000	0.29	--	--	--	--	--	--	--
	1700	0.75	--	--	--	--	--	--	--
III	10	0.12	10	1	0.12	10	1	0	0.15
	40	0.15	40	4	0.23	40	4	0	0.11
	100	0.20	100	10	0.19	100	9	1	0.10
	200	0.20	200	20	0.18	--	--	--	--
	300	--	--	--	--	300	27	3	0.18
	400	--	400	40	0.22	--	--	--	--
	500	0.19	--	--	--	--	--	--	--
	630	--	--	--	--	630	57	6	0.29
	1000	0.20	1000	100	0.32	1000	90	10	0.31
	1700	0.30	1700	170	0.40	1700	153	17	0.32

* Permanent (nonelastic) deformation.

061760-C

Table 5

Summary of Traffic Test Results

Section No.	Lane	Avg Subgrade CBR	% Design Thickness for 10,000-lb Single-Wheel Load*	First Indication of Failure: Applications of Test Traffic**	First Indication of Failure: Maximum Deflection in.	First Indication of Failure: Maximum Deformation in.	First Indication of Failure: Base Course CBR	First Indication of Failure: Base Course Density in % of Modified AASHO	Complete Failure: Applications of Test Traffic**	Complete Failure: Maximum Deflection in.	Complete Failure: Maximum Deformation in.	Complete Failure: Base Course CBR	Complete Failure: Base Course Density in % of Modified AASHO
[illegible]	A	6	[illegible]	[illegible]	[illegible]	[illegible]	37	102.0	[illegible]	0.280	2.80	9	94.0
	B	[illegible]	[illegible]	[illegible]	[illegible]	0.130	39	97.5	50	[illegible]	0.58	30	96.7
	C	[illegible]	[illegible]		[illegible]	[illegible]	29	99.4	[illegible]	0.820	0.80	20	98.7
[illegible]	A	6	[illegible]	[illegible]	[illegible]	0.258	90	103.5	1700		No failure		
	B	[illegible]	[illegible]	[illegible]	[illegible]	0.250	[illegible]	[illegible]	630	0.530	1.20	38	101.0
	C	6	[illegible]	[illegible]	0.438	0.250	92	102.8	630	0.550	1.30	22	99.2
[illegible]	A	6	[illegible]	1700		No indication of failure			1700		No failure		
	B	6	[illegible]	1000	[illegible]	[illegible]	[illegible]	105.0	1700		No failure		
	C	[illegible]	[illegible]	1000	0.310	0.310	100	102.0	1700		No failure		

* Design thickness for a 10,000-lb single-wheel load and a 6 CBR subgrade is 13 in.

** See paragraph 4 and table [illegible] for composition of "applications of test traffic."

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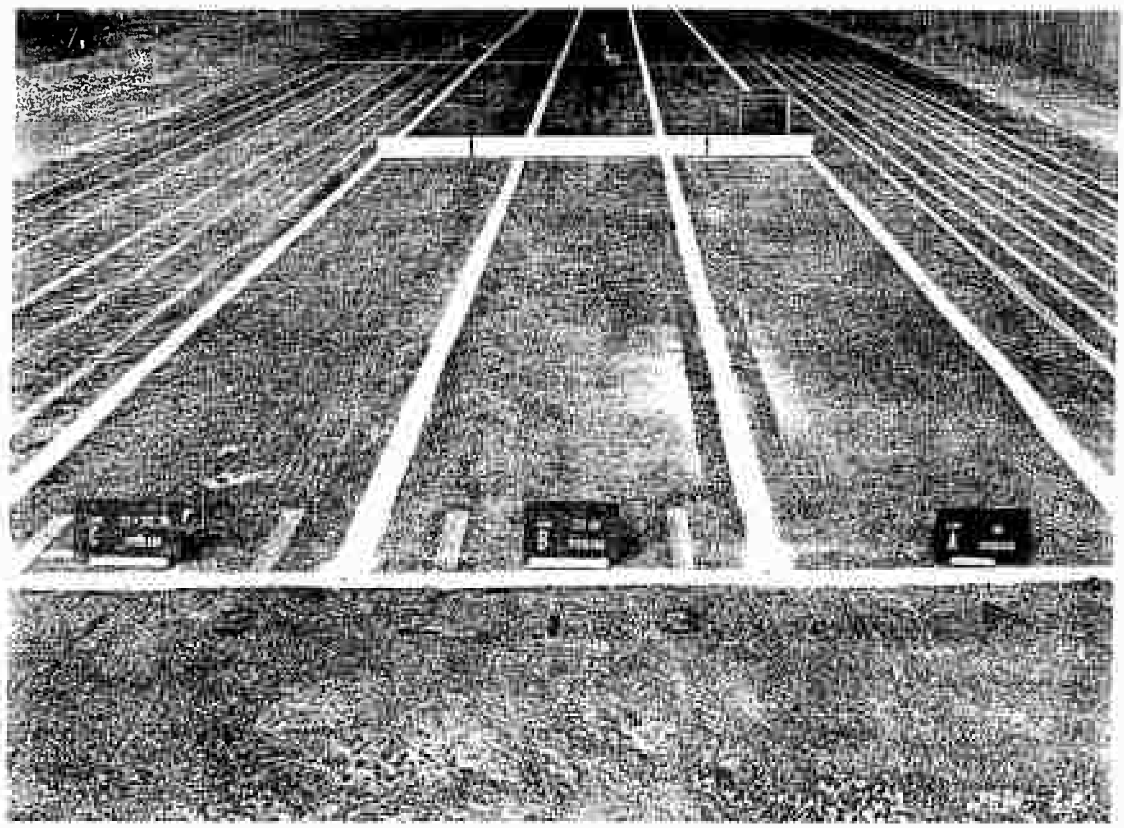
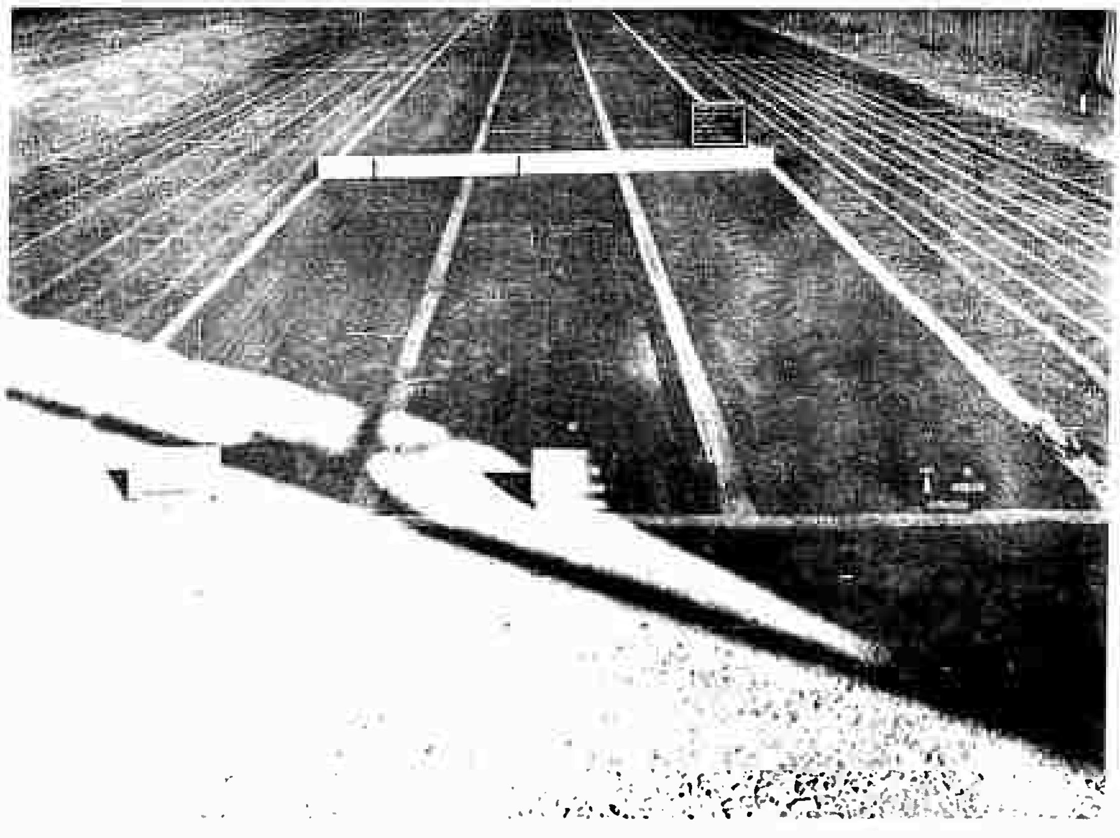
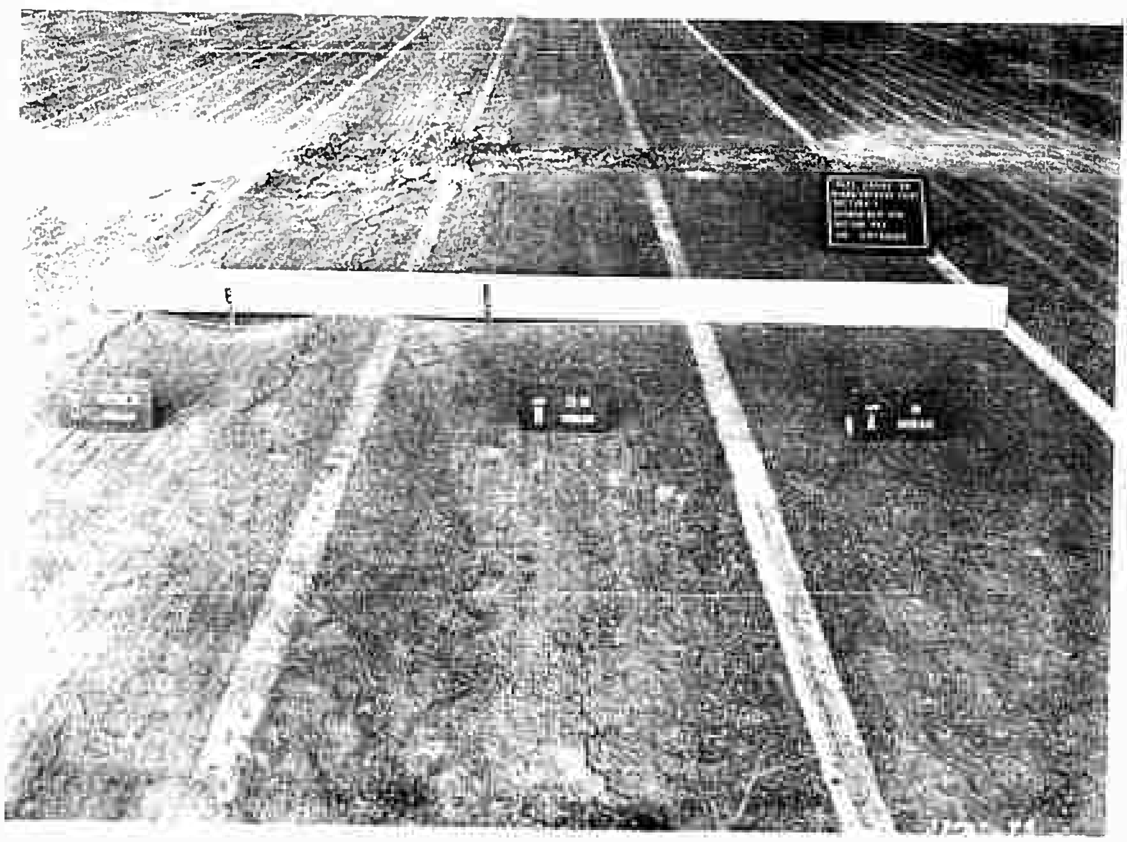


Photograph 1. Section I before application of traffic



Photograph 2. Section I after 4 applications of traffic. Note first indication of failure in lane A

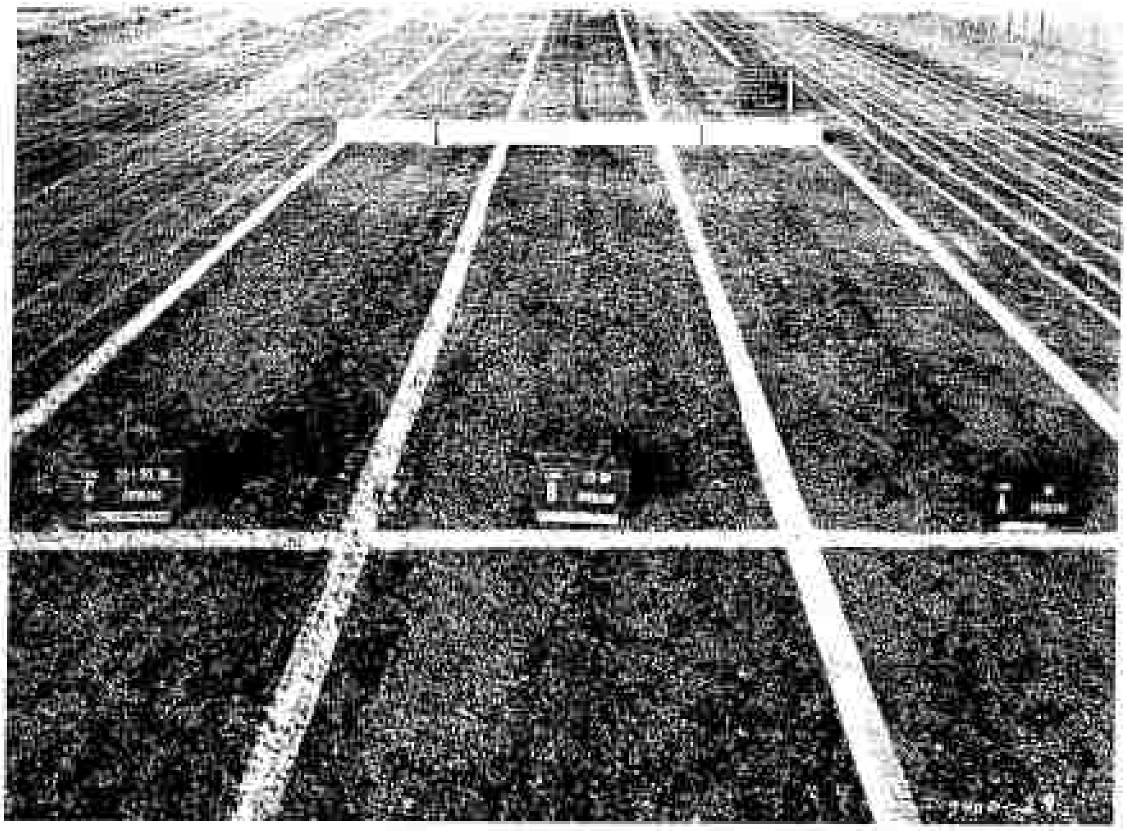
Photograph [illegible]. Incipient failure at sta [illegible]+35, lanes B and C, section I, after [illegible] applications of traffic



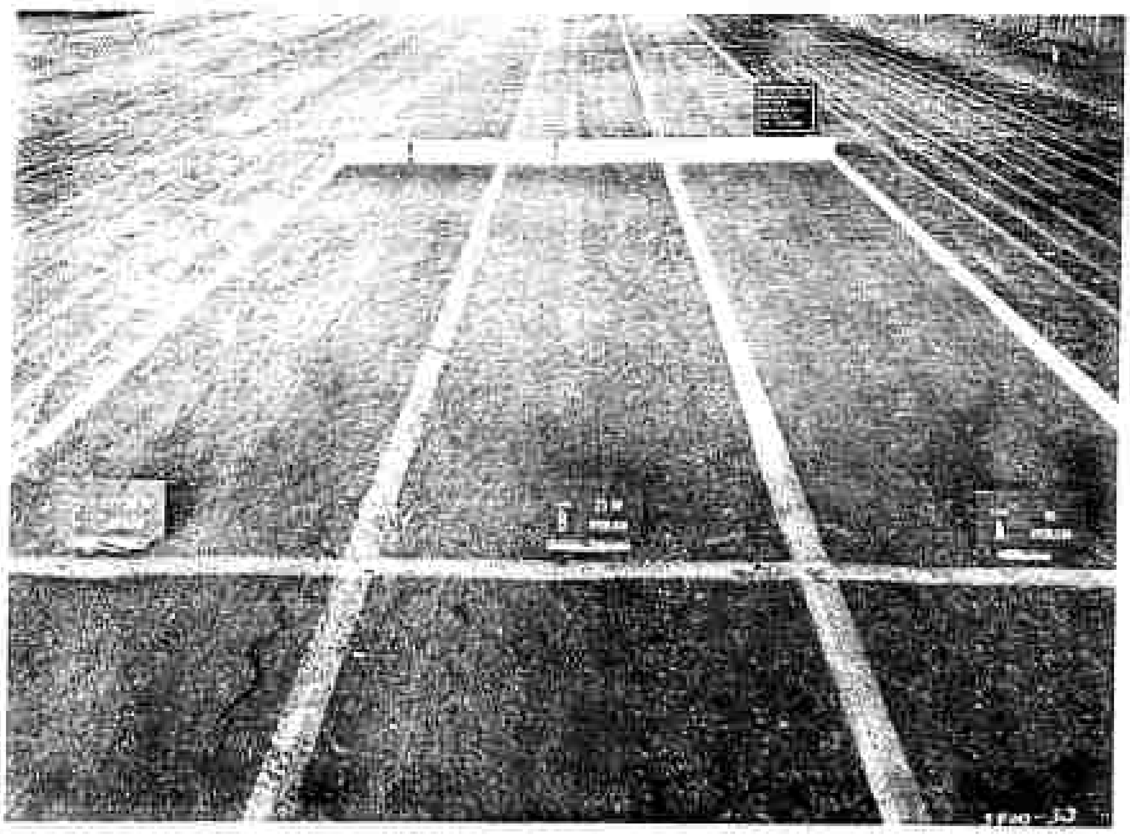
Photograph [illegible]. Complete failure of lanes B and C, section I, after [illegible] applications of traffic

Photograph [illegible]. Localized failure at sta [illegible]+35, lane A, section I, after [illegible] applications of traffic

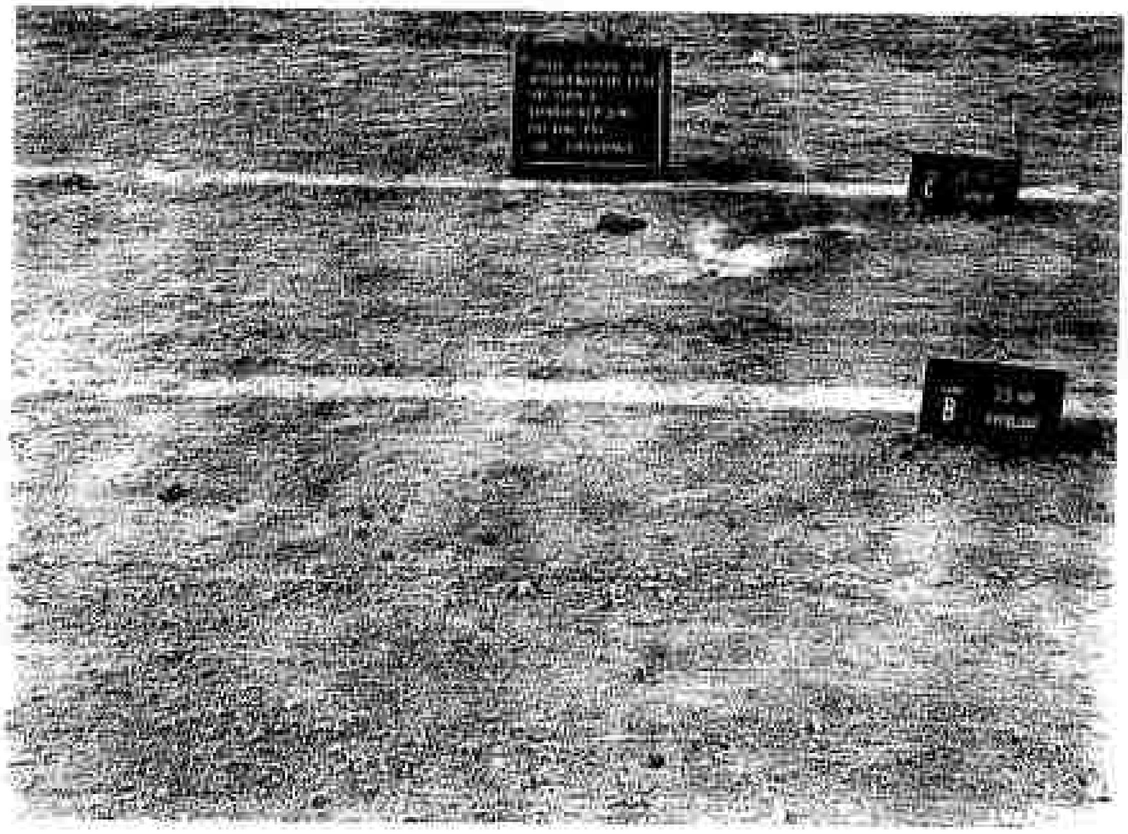
Photograph [illegible]. Complete failure of lane A, section I, after [illegible] applications of traffic



Photograph 1. Section II before application of traffic

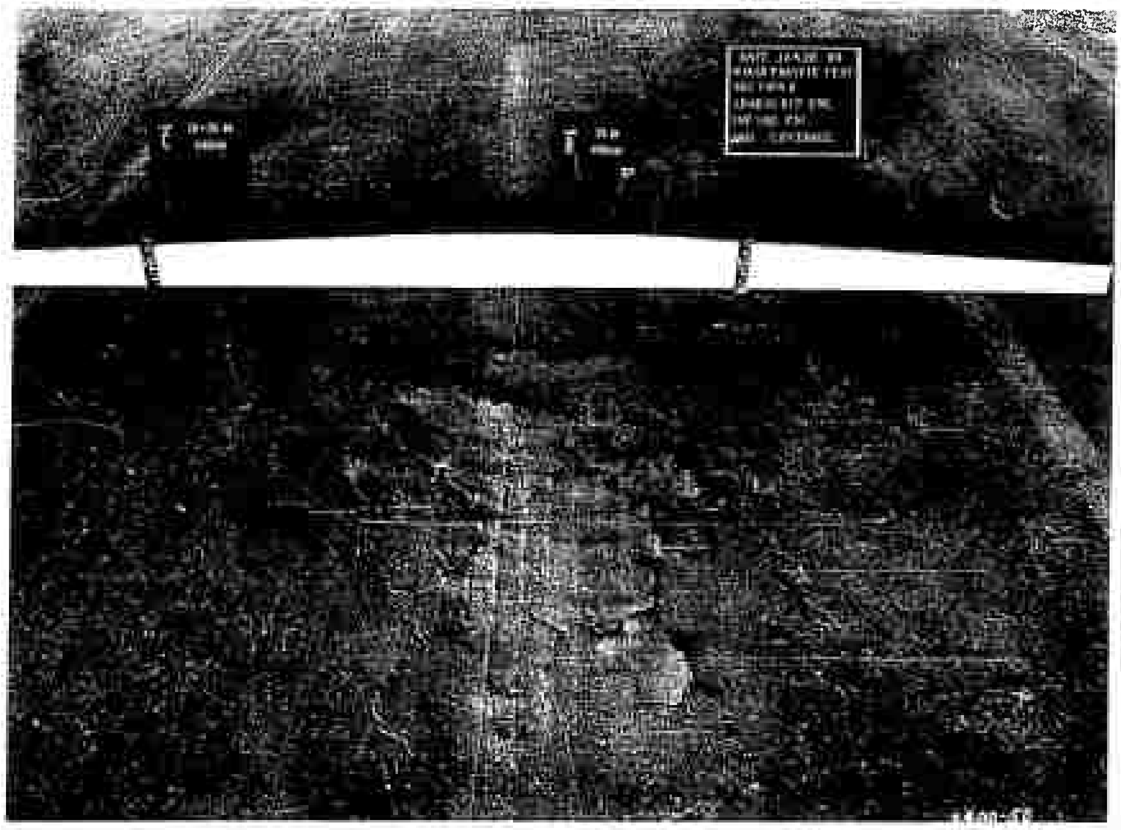


Photograph 2. Section II after 4[illegible] applications of traffic



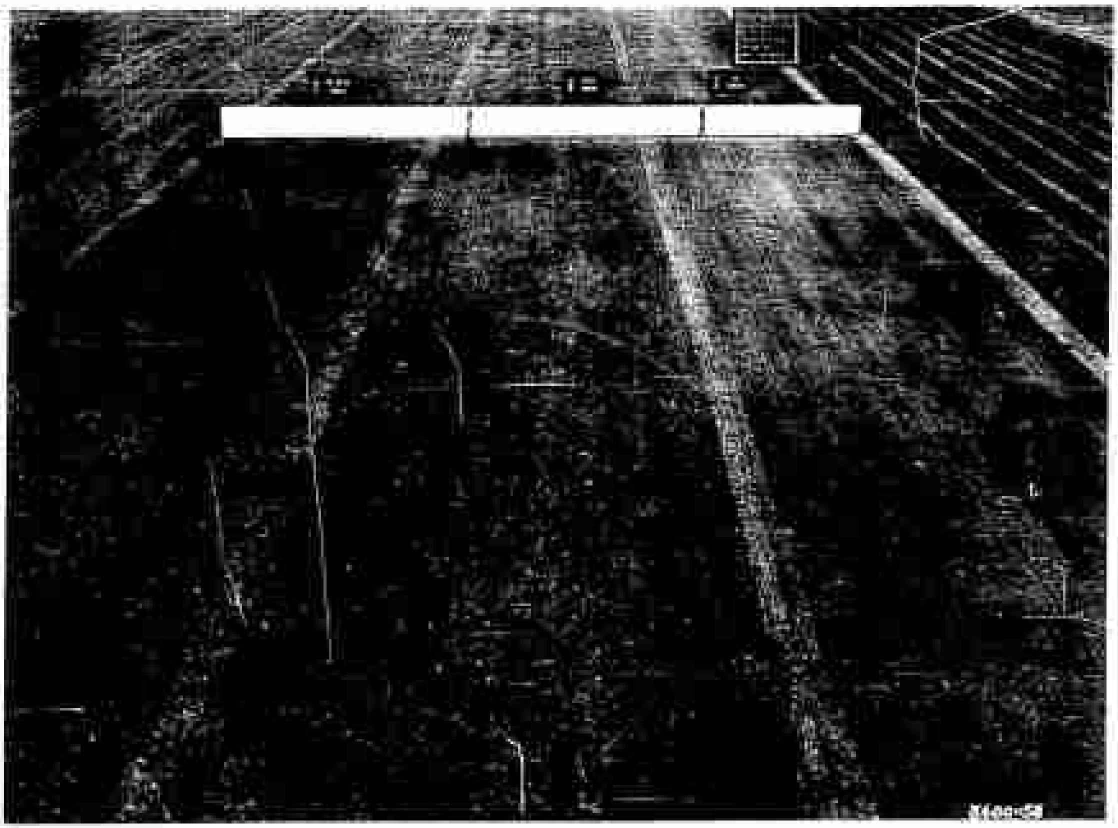
Photograph [illegible]. First indication of failure in lanes B and C, section [illegible], after [illegible] applications of traffic

Photograph [illegible]. Progressive failure at sta [illegible], lanes B and C, section [illegible], after [illegible] applications of traffic

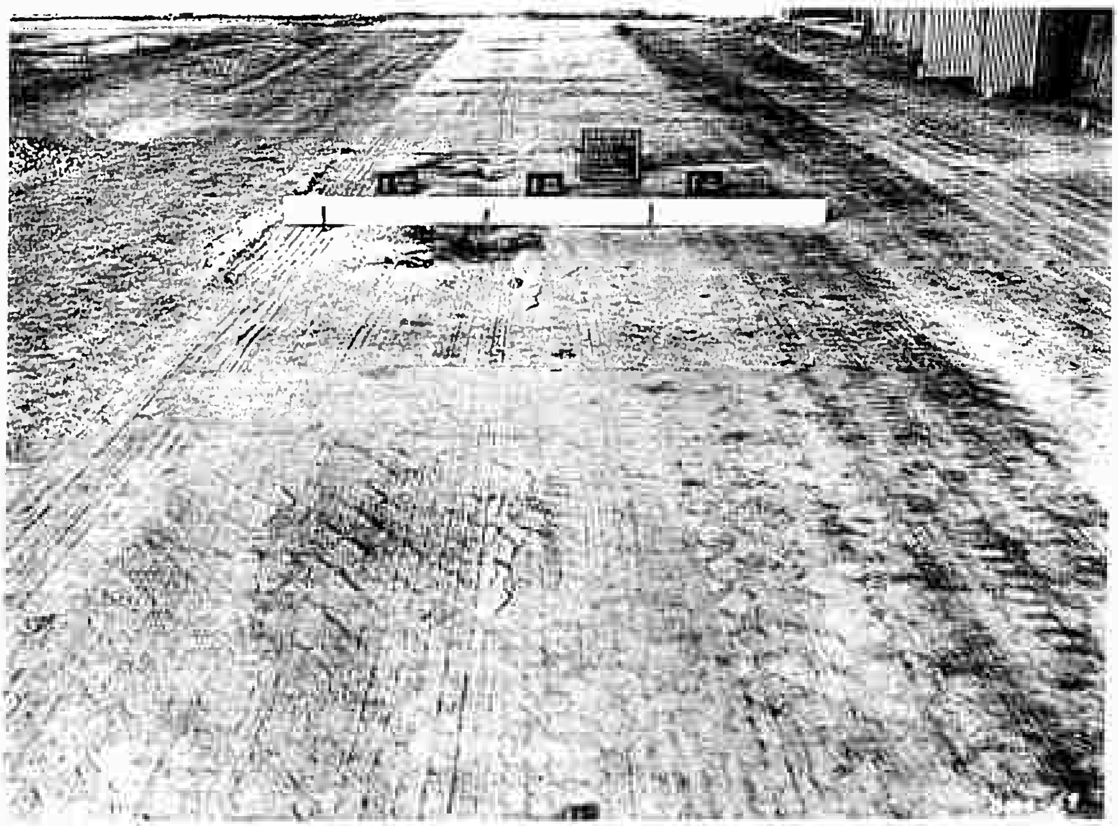


Photograph 11. Progressive failure at sta [illegible], lanes B and C, section II, after [illegible] applications of traffic

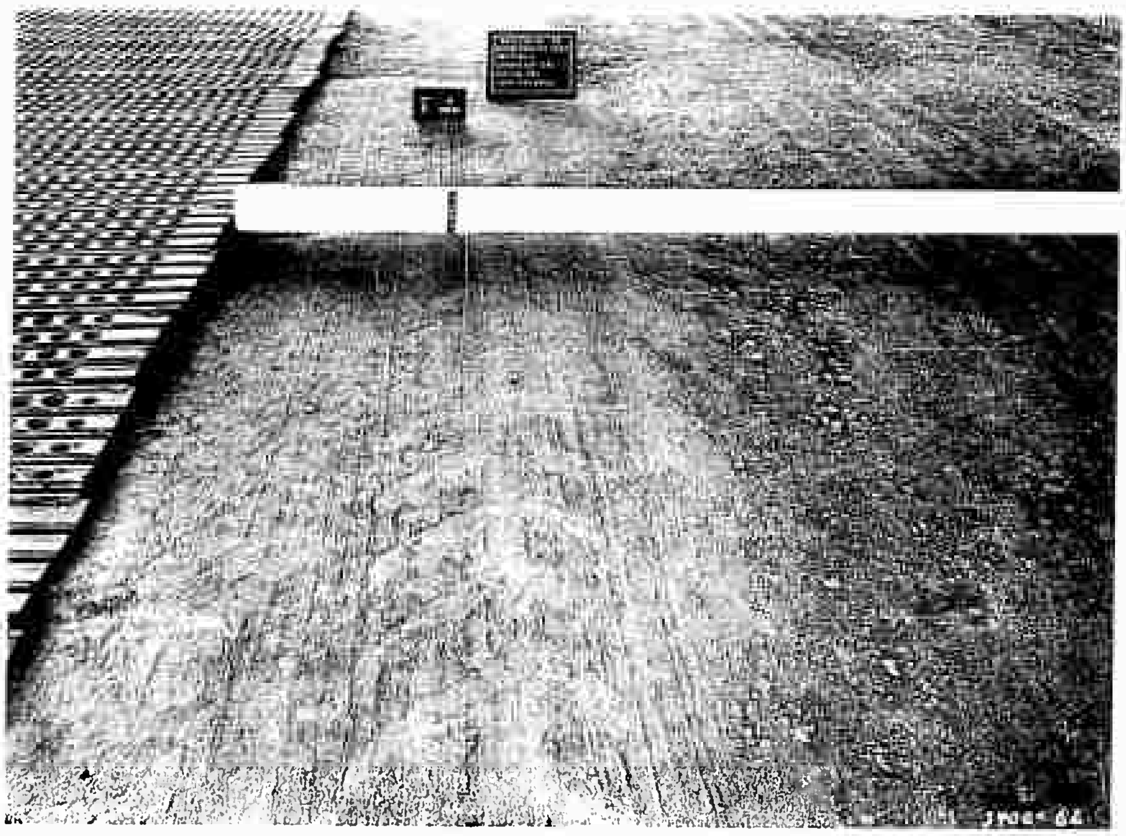
Photograph 12. Localized failure at sta 0+[illegible], lanes B and C, section II, after 2[illegible] applications of traffic



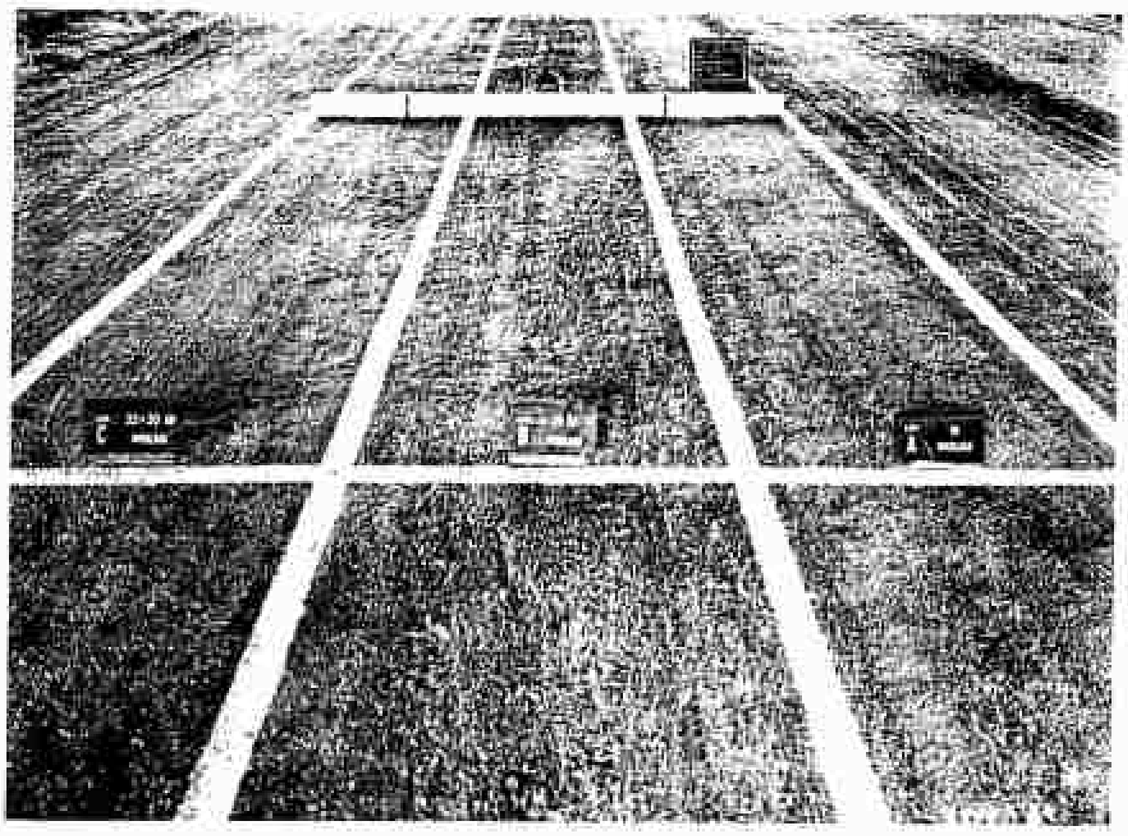
Photograph 13. Section II after 200 applications of traffic



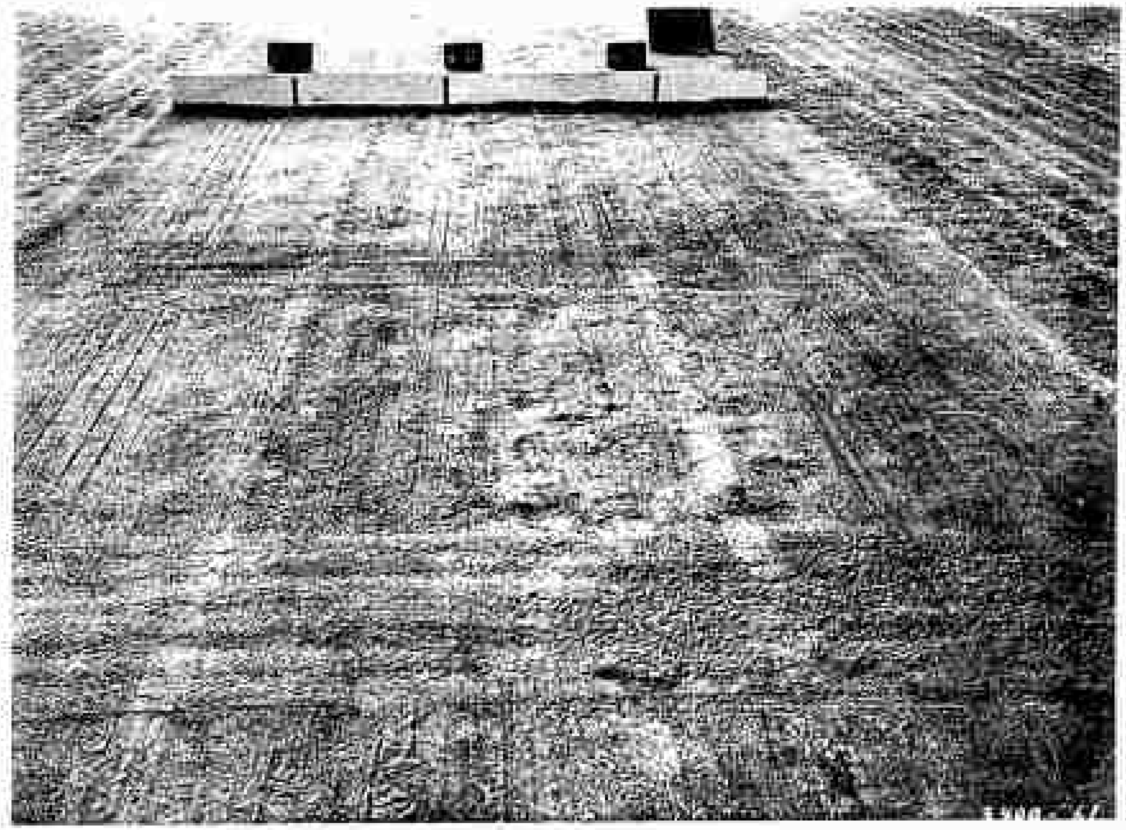
Photograph 14. Complete failure of lanes B and C, section II, after [illegible] applications of traffic



Photograph 15. Lane A, Section II, after 1000 applications of traffic

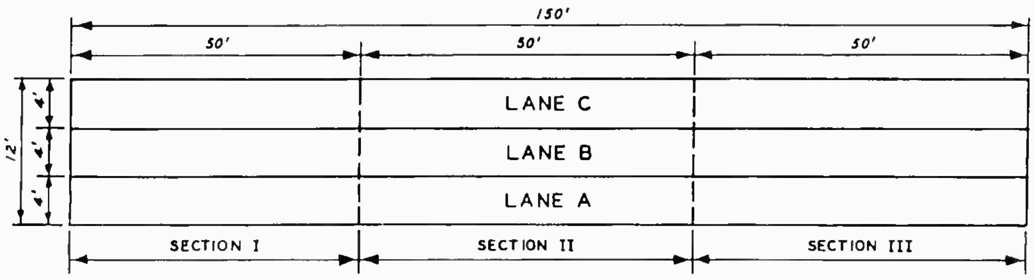


Photograph 16. Section III before application of traffic

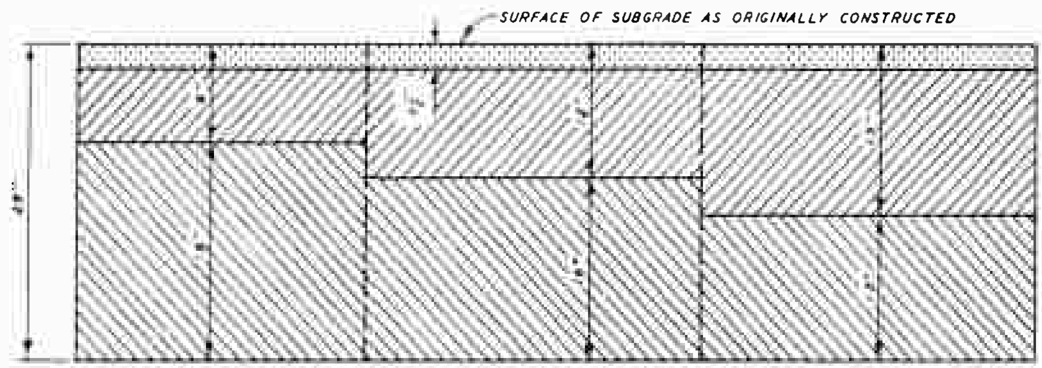


Photograph 17. Section III after 1000 applications of traffic

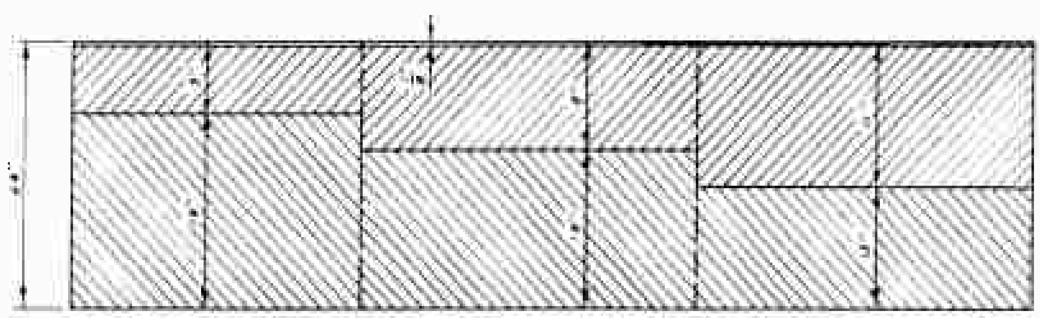
Photograph 18. Small cracks in lane C, section III, after [illegible] applications of traffic



a. PLAN



b. SECTION PRIOR TO REMOVAL OF ASPHALTIC CONCRETE

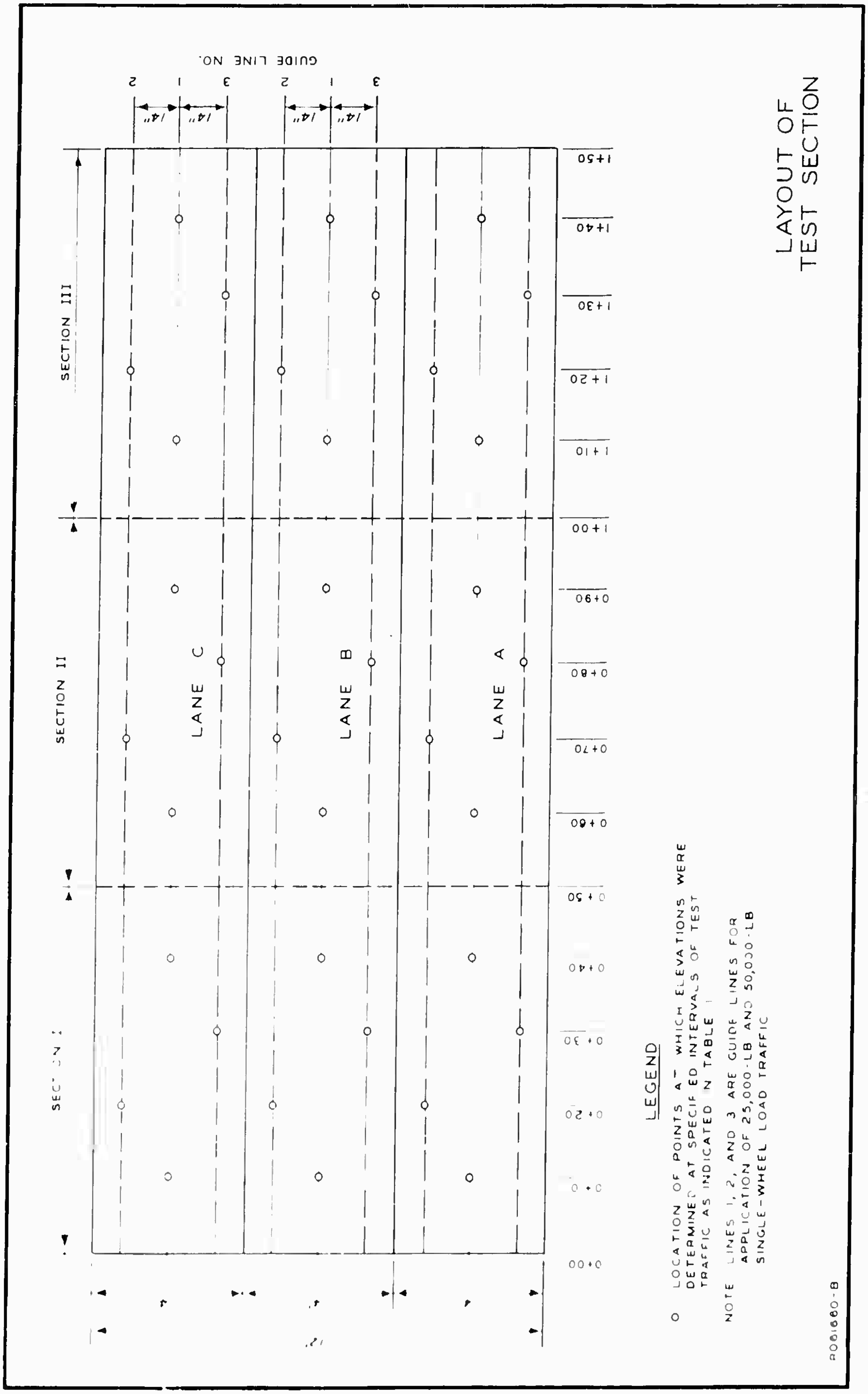


c. SECTION AFTER REMOVAL OF ASPHALTIC CONCRETE

LEGEND

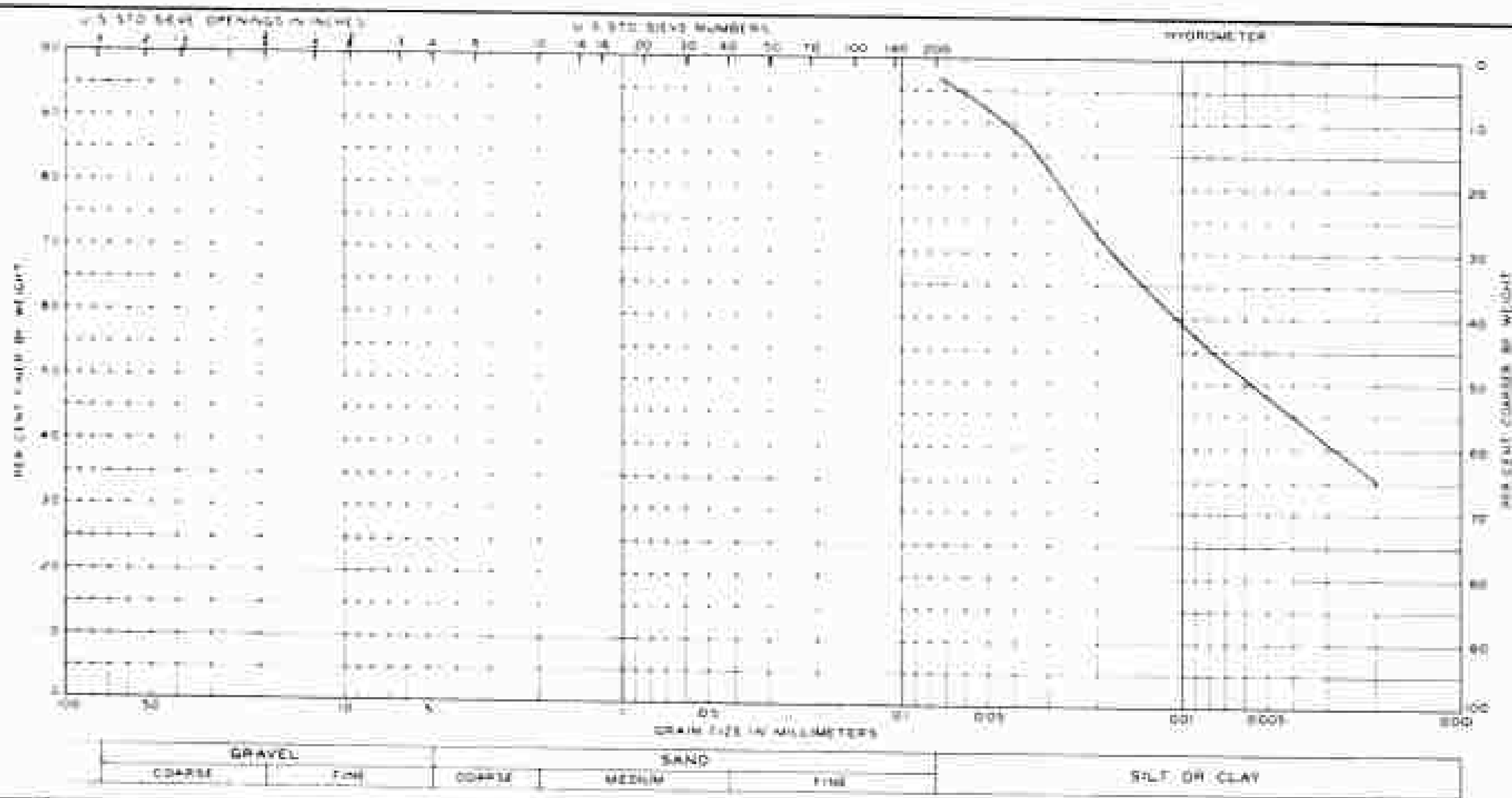
- ASPHALTIC CONCRETE
- SEAL COAT
- CRUSHED STONE BASE COURSE
- CLAY SUBGRADE

PLAN AND PROFILES OF
TEST SECTION



LAYOUT OF TEST SECTION

PLATE 2

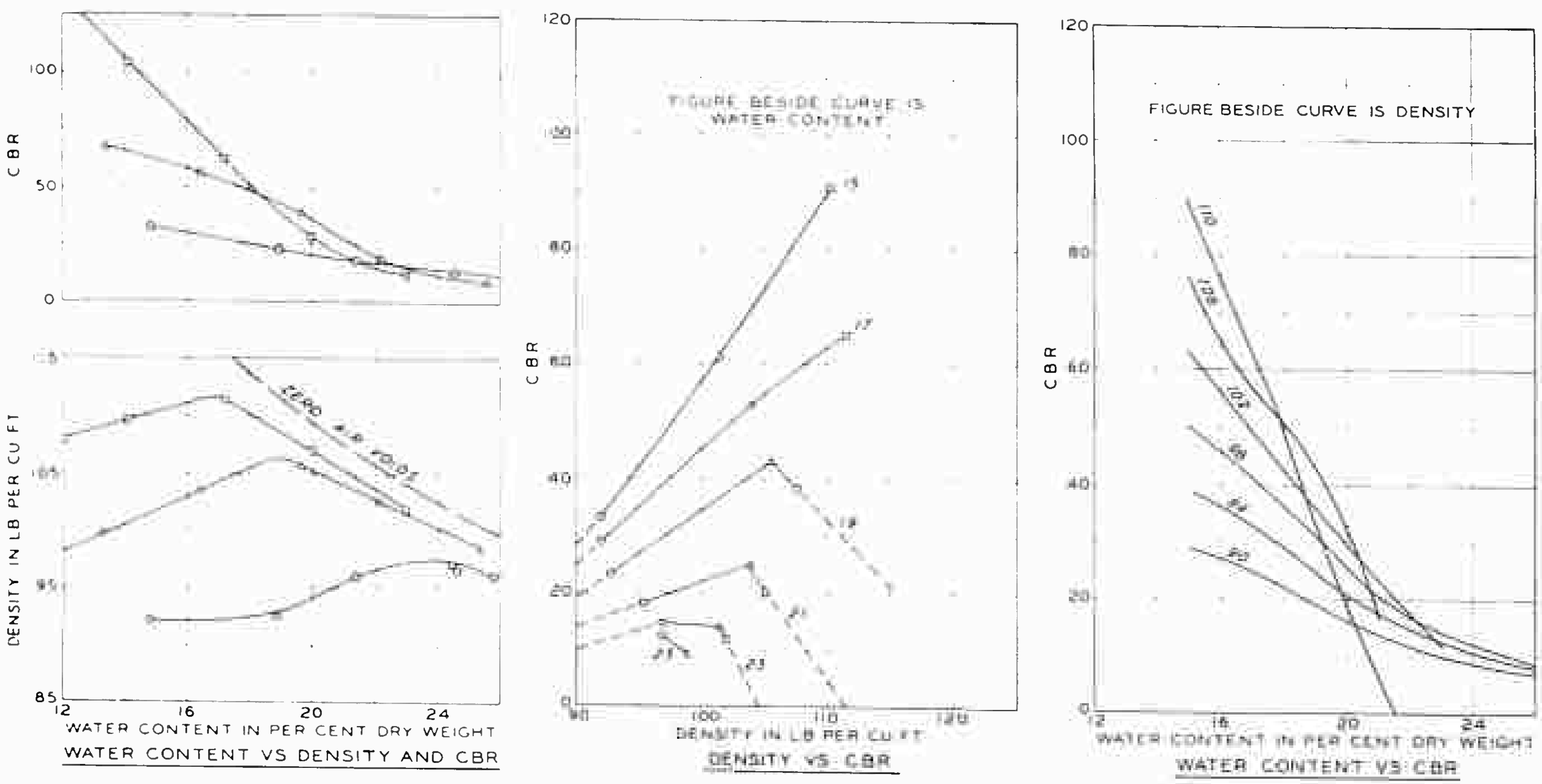


NUMBER	DEPTH	NATURAL MOISTURE	L.L.	P.L.	P.I.	CLASSIFICATION
	RK1665-C		62	25	37	CH

GRADATION OF SUBGRADE MATERIAL

LONG LAKE BUCKSHOT CLAY

PLATE 3

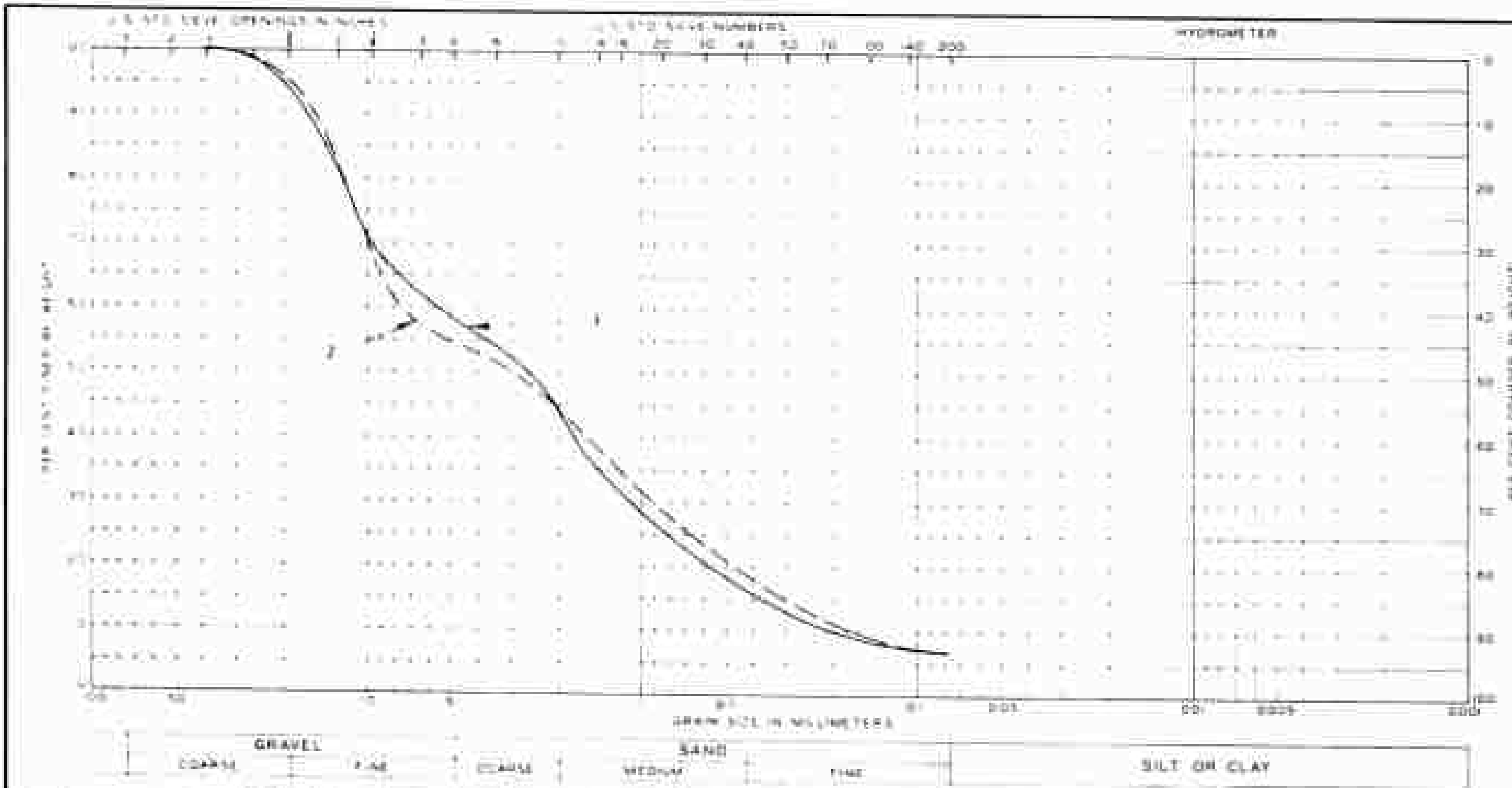


LEGEND

SYMBOL	LAYERS	BLOWS PER LAYER	WT HAMMER, LB	DROP, IN
○	5	12	10	18
△	5	26	10	18
□	5	55	10	18(MOD AASHO)

CBR (UNSOAKED),
WATER CONTENT, AND DENSITY
SUBGRADE MATERIAL
(LONG LAKE BUCKSHOT CLAY)

PLATE 4

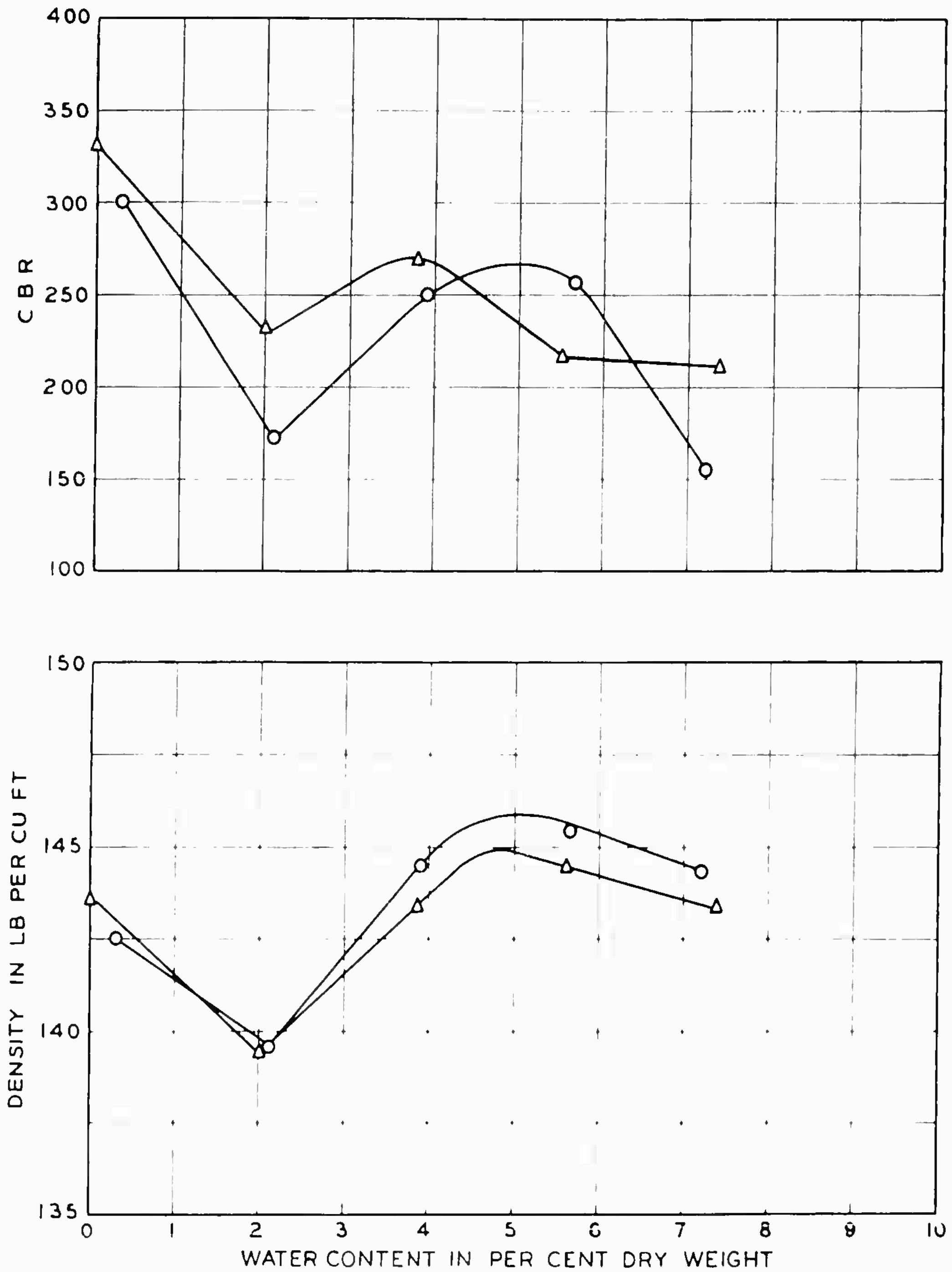


NUMBER	DEPTH	NATURAL MOISTURE	LL	PL	PI	CLASSIFICATION
1			16	14	2	GW-GM
2			16	14	2	GW-GM
	361660-E					

TYPICAL GRADATIONS OF BASE COURSE MATERIAL

BLEND 2

FRANKLIN COUNTY, TENN., CRUSHED LIMESTONE

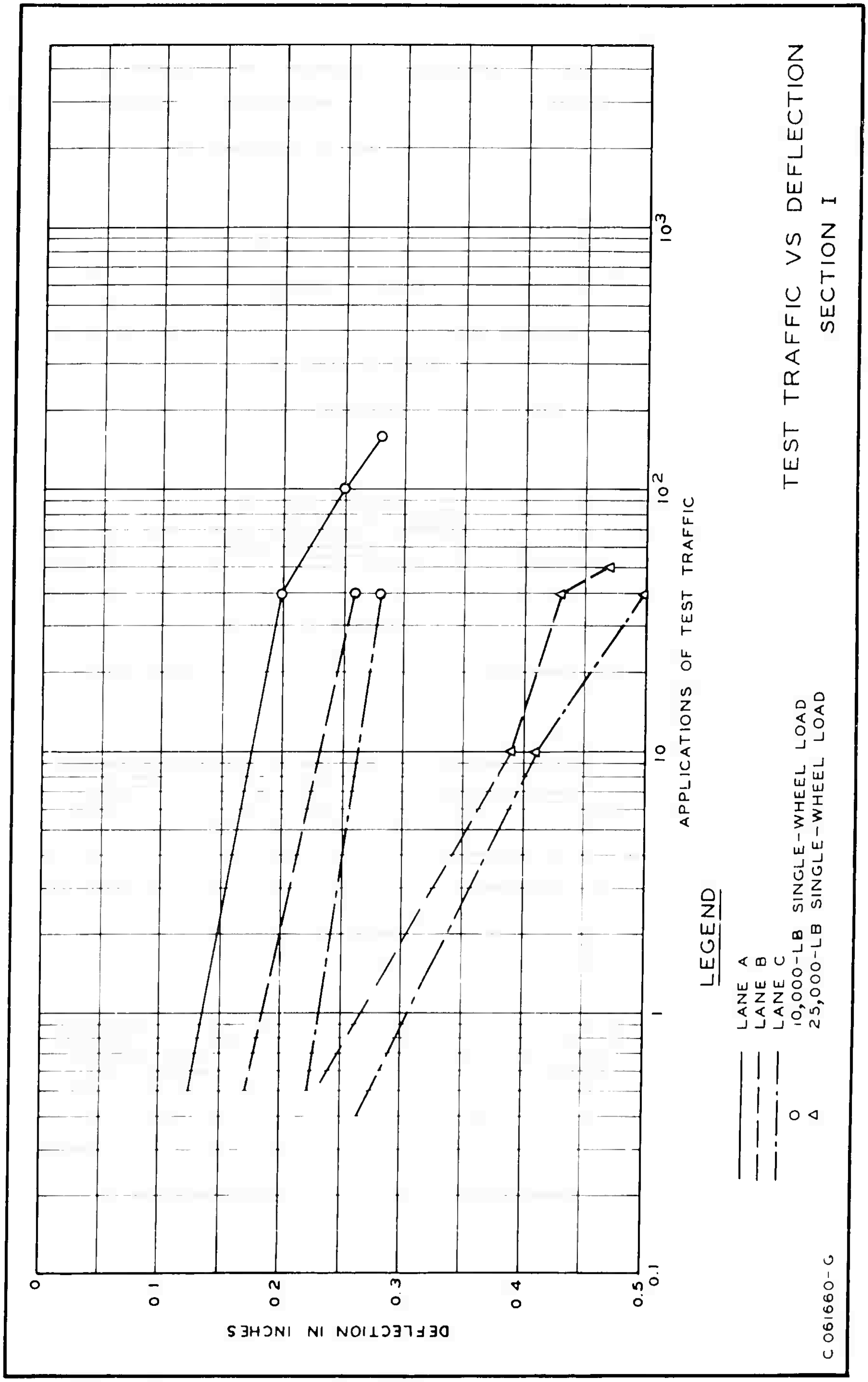


WATER CONTENT VS DENSITY AND CBR

CBR AND MODIFIED AASHO
COMPACTION CHARACTERISTICS
BASE COURSE MATERIAL

R061880-F

PLATE 6


TEST TRAFFIC VS DEFLECTION
SECTION I
APPLICATIONS OF TEST TRAFFIC
DEFLECTION IN INCHES
0.1
1
10
10^2
10^3
0
0.1
0.2
0.3
0.4
0.5
LEGEND
LANE A
LANE B
LANE C
O 10,000-LB SINGLE-WHEEL LOAD
Δ 25,000-LB SINGLE-WHEEL LOAD
C 061660-G

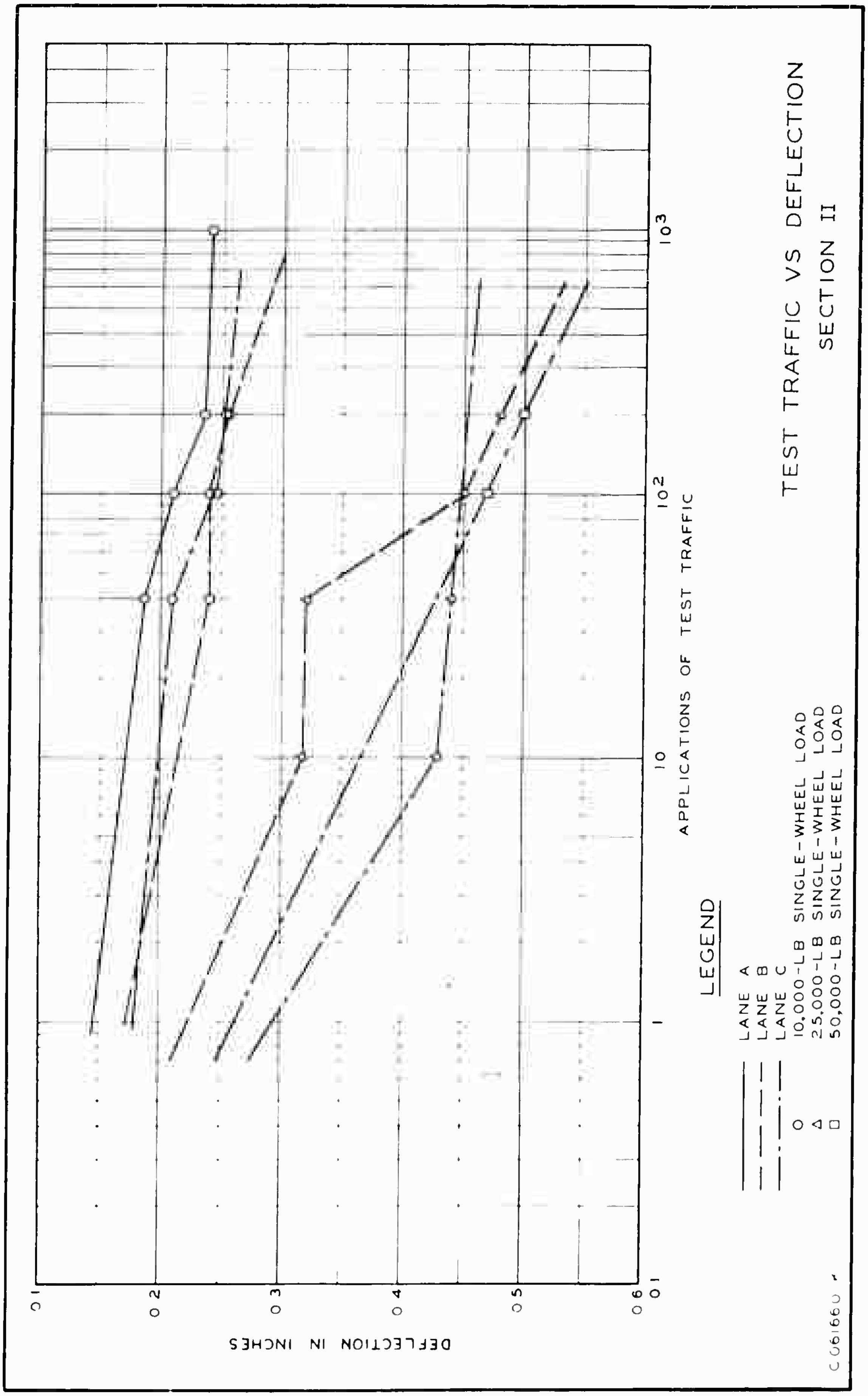
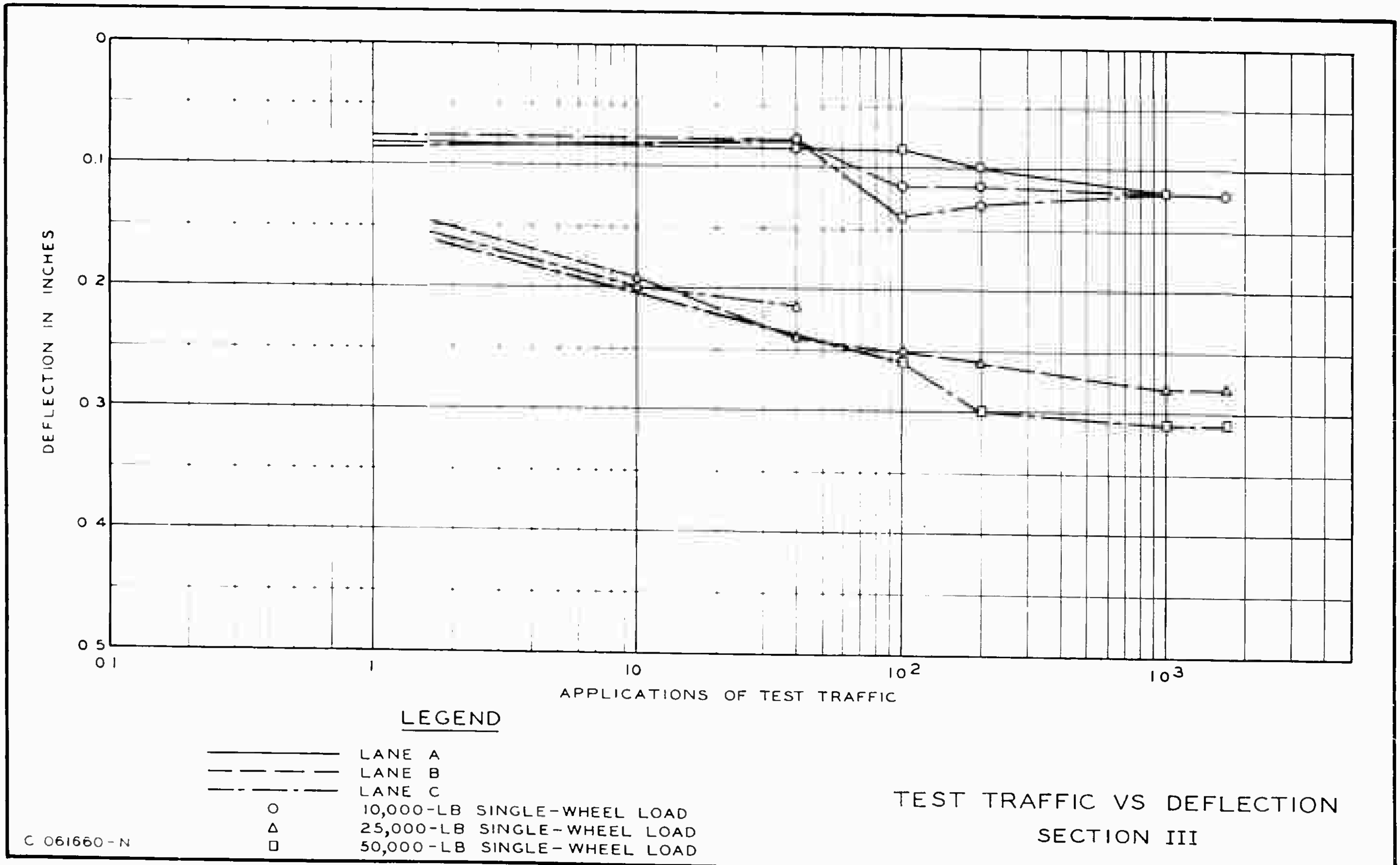

TEST TRAFFIC VS DEFLECTION
SECTION II
APPLICATIONS OF TEST TRAFFIC
DEFLECTION IN INCHES
1
10
10²
10³
0.1
0.2
0.3
0.4
0.5
0.6
LEGEND
LANE A
LANE B
LANE C
○ 10,000-LB SINGLE-WHEEL LOAD
△ 25,000-LB SINGLE-WHEEL LOAD
□ 50,000-LB SINGLE-WHEEL LOAD

PLATE 8



TEST TRAFFIC VS DEFLECTION
SECTION III

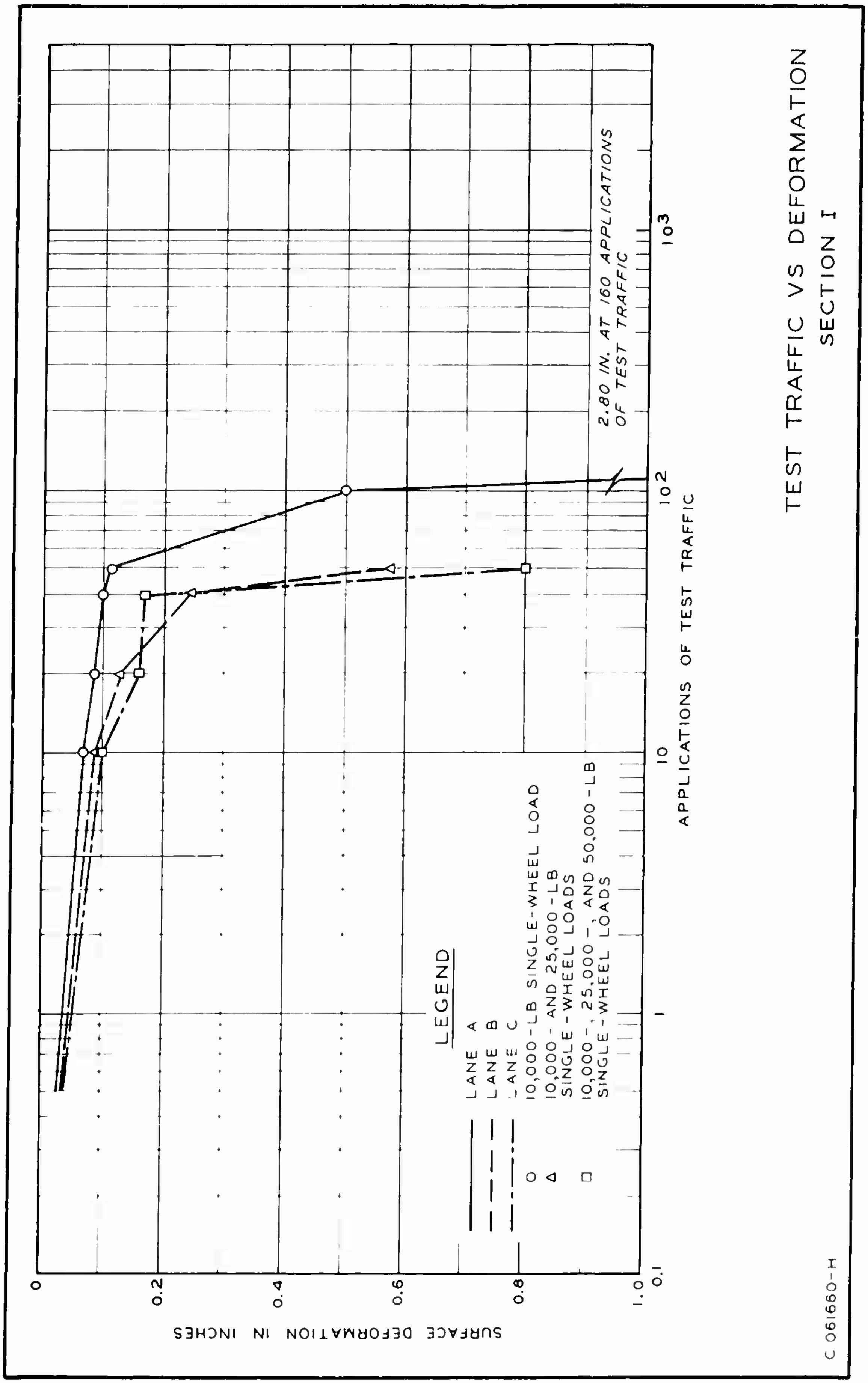
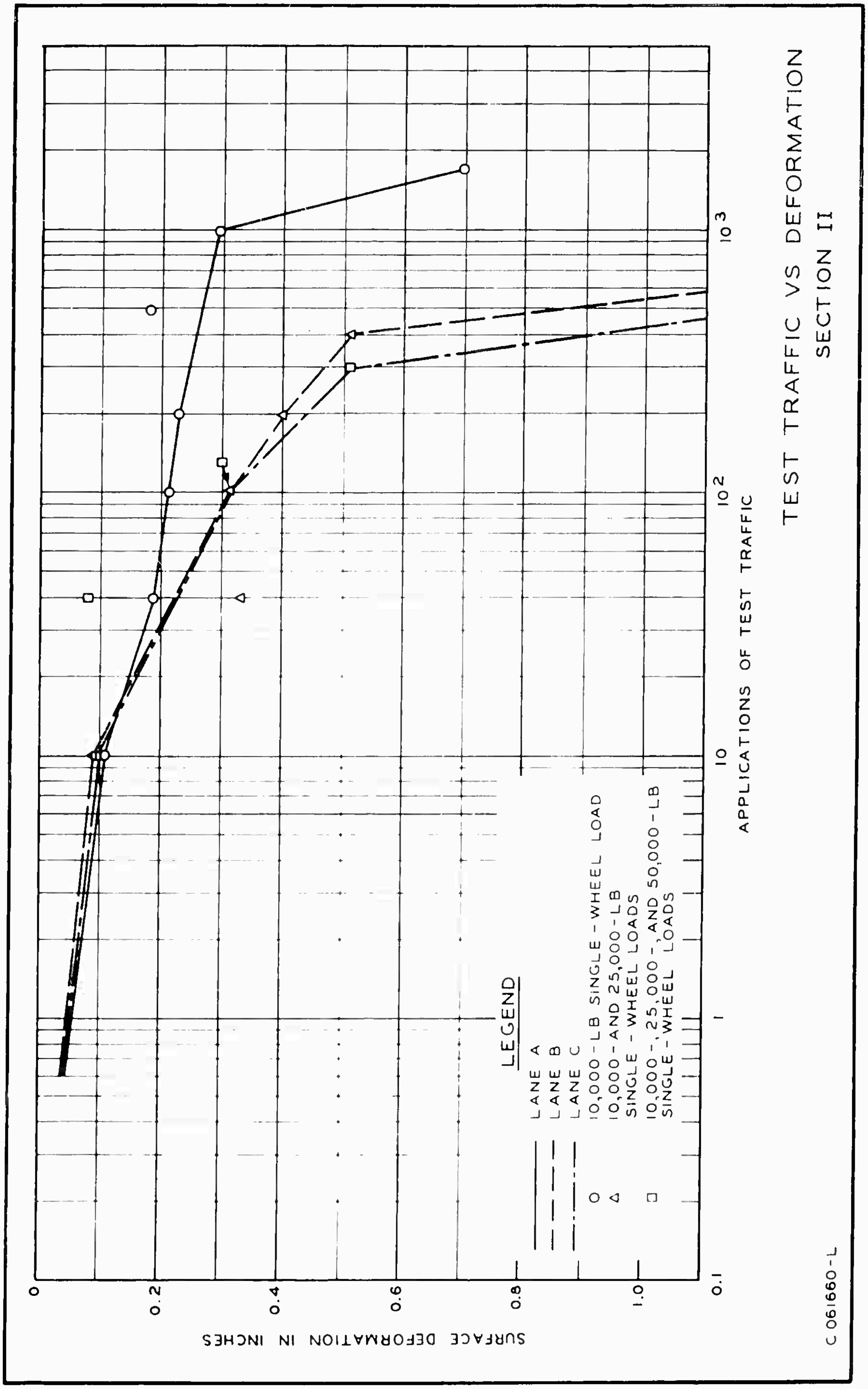
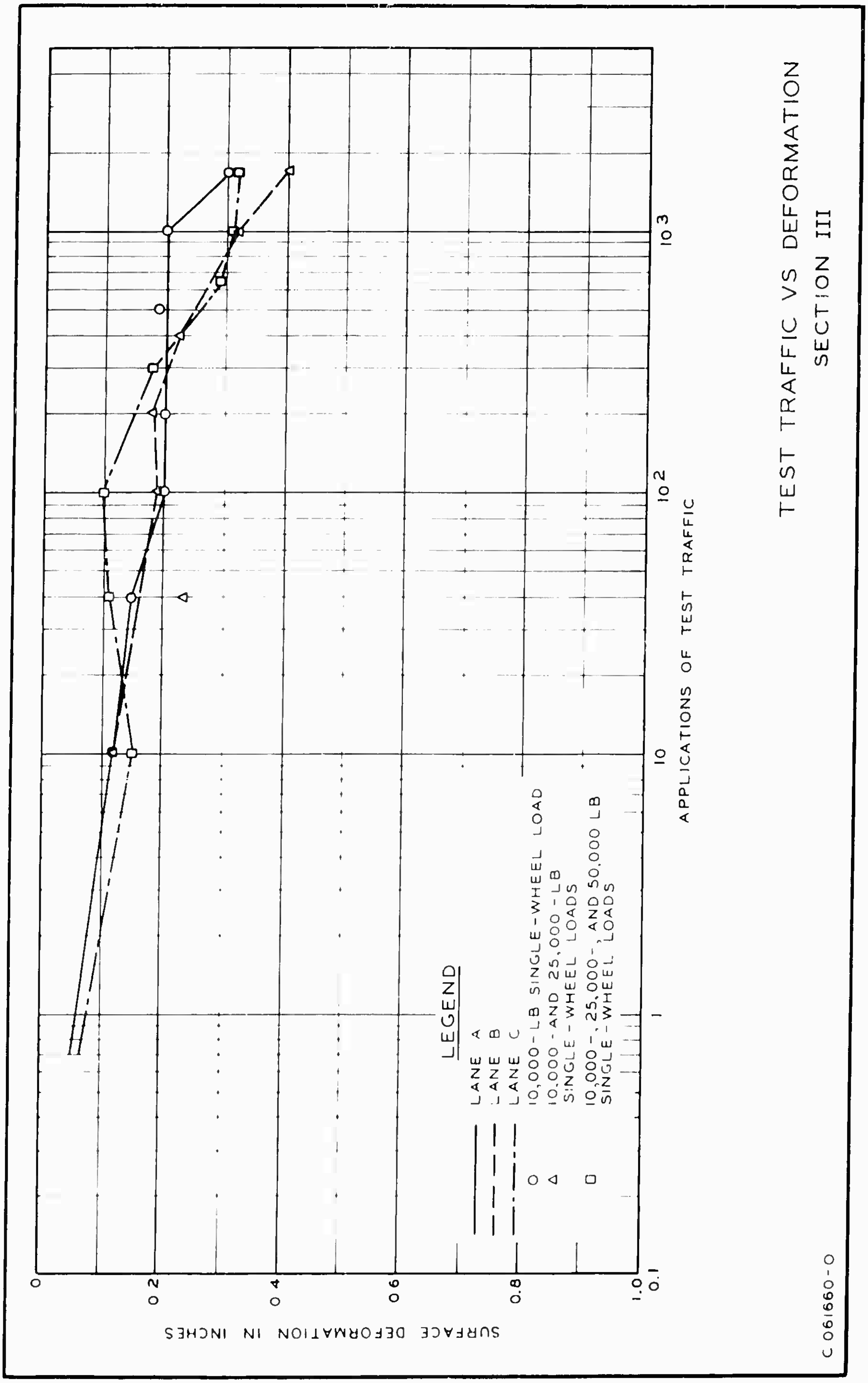

TEST TRAFFIC VS DEFORMATION
SECTION I
SURFACE DEFORMATION IN INCHES
0
0.2
0.4
0.6
0.8
1.0
APPLICATIONS OF TEST TRAFFIC
0.1
1
10
10²
10³
2.80 IN. AT 160 APPLICATIONS OF TEST TRAFFIC
LEGEND
LANE A
LANE B
LANE C
10,000-LB SINGLE-WHEEL LOAD
10,000- AND 25,000-LB SINGLE-WHEEL LOADS
10,000-, 25,000-, AND 50,000-LB SINGLE-WHEEL LOADS
C 061660-H

PLATE 10

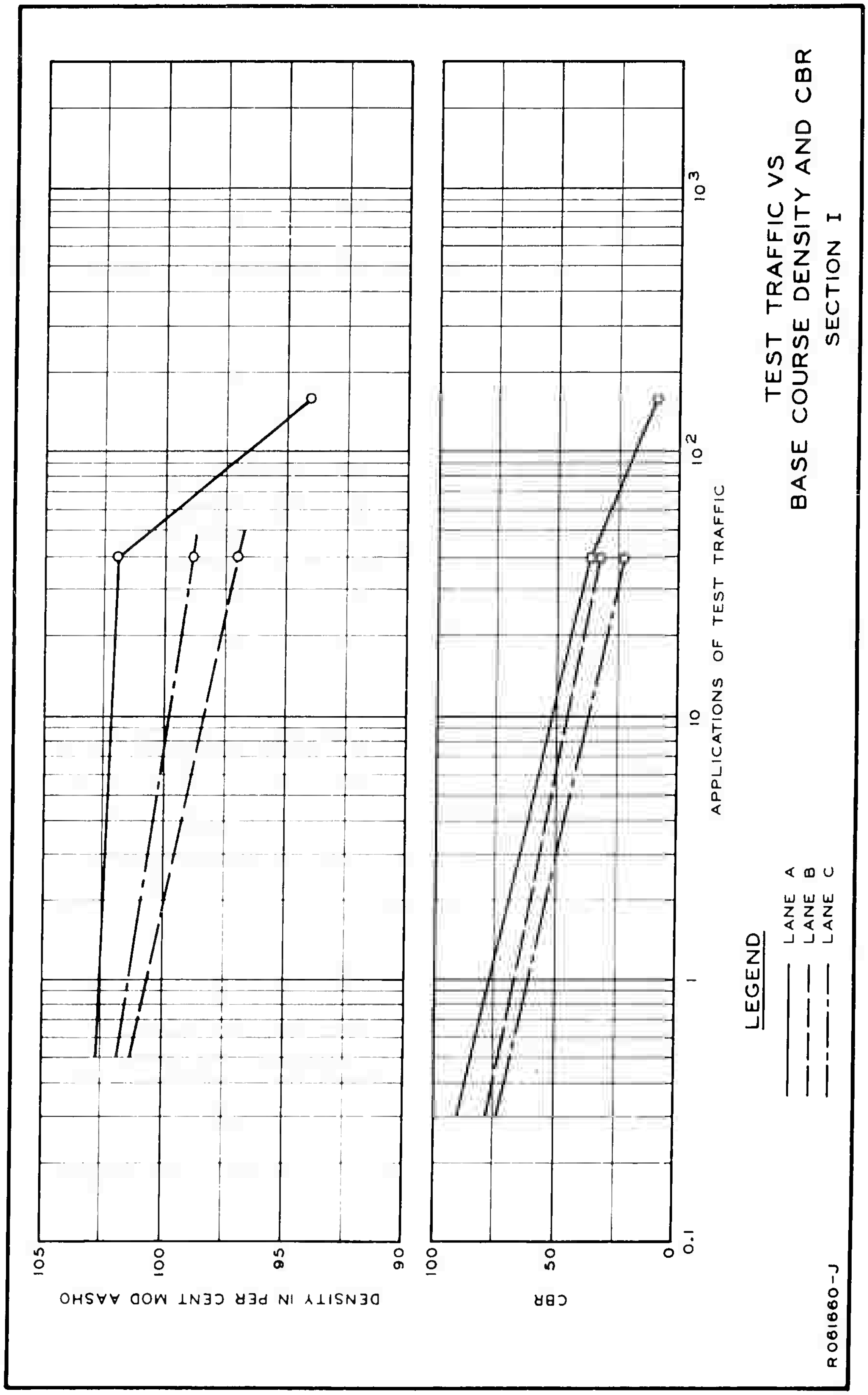


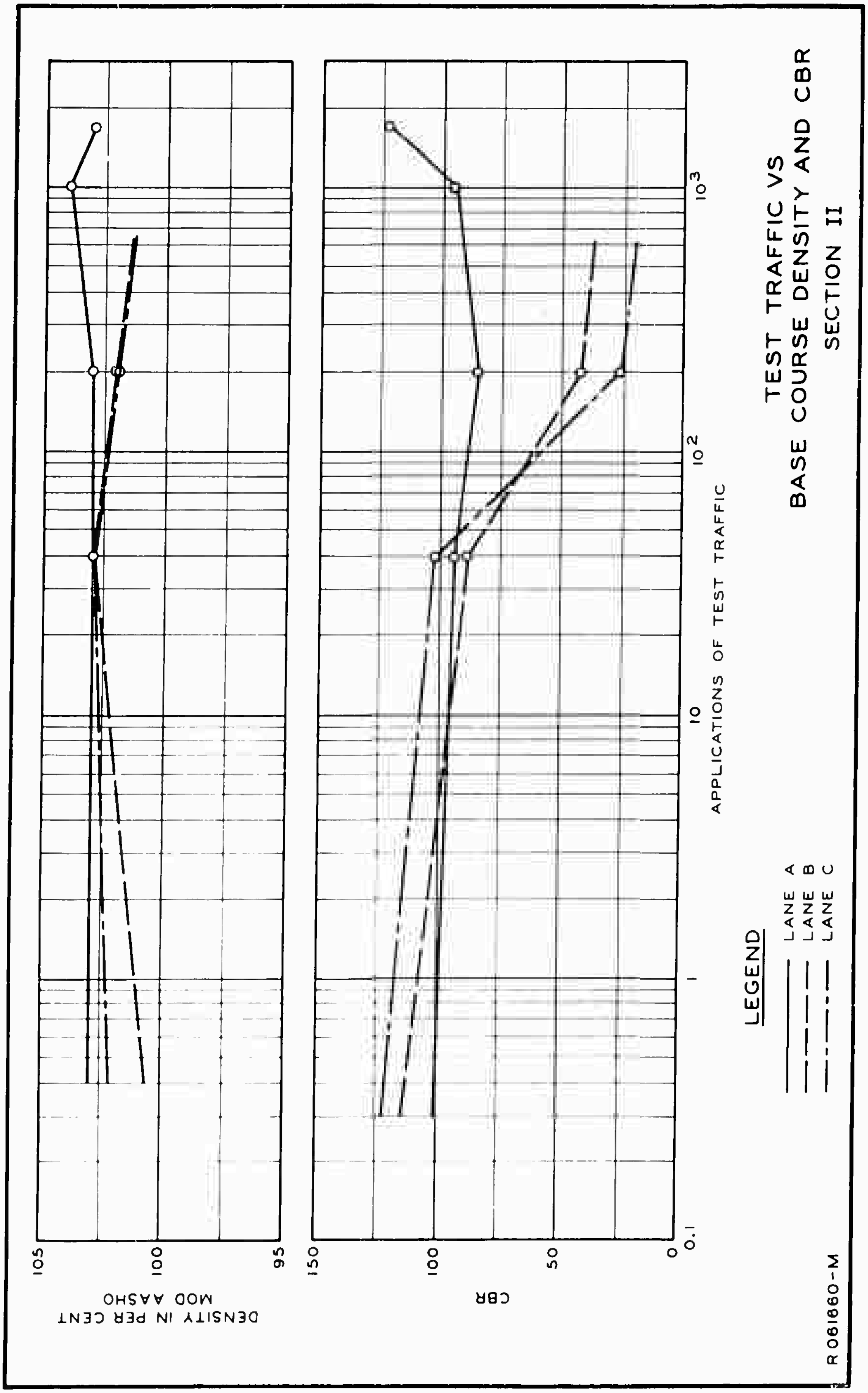
TEST TRAFFIC VS DEFORMATION
SECTION II



TEST TRAFFIC VS DEFORMATION
SECTION III
LEGEND
LANE A
LANE B
LANE C
10,000-LB SINGLE-WHEEL LOAD
10,000- AND 25,000-LB SINGLE-WHEEL LOADS
10,000-, 25,000-, AND 50,000 LB SINGLE-WHEEL LOADS
APPLICATIONS OF TEST TRAFFIC
SURFACE DEFORMATION IN INCHES
0
0.2
0.4
0.6
0.8
1.0
0.1
1
10
10^2
10^3
C 061660-0

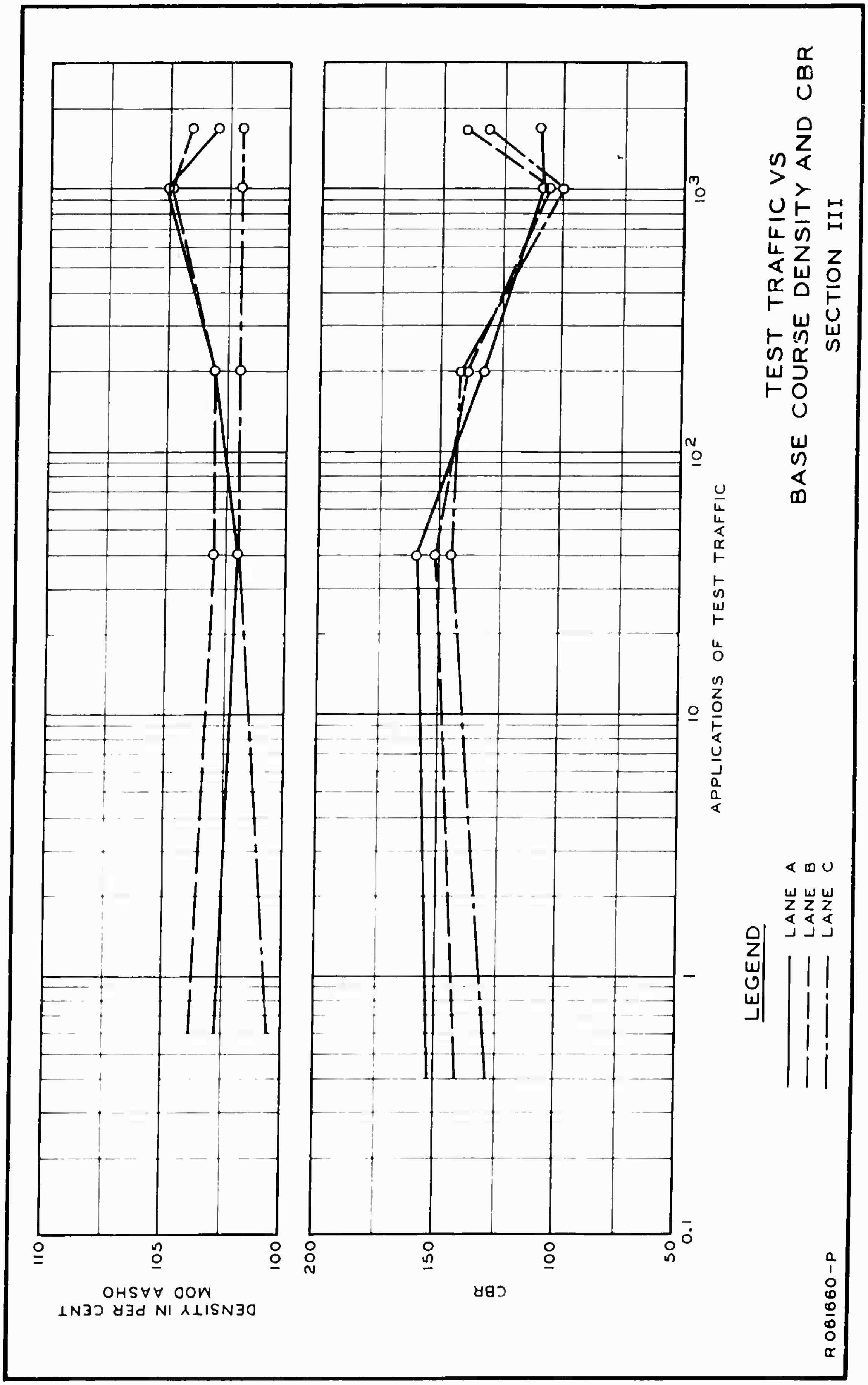
PLATE 12


TEST TRAFFIC VS
BASE COURSE DENSITY AND CBR
SECTION I
LEGEND
LANE A
LANE B
LANE C
DENSITY IN PER CENT MOD AASHO
105
100
95
90
CBR
100
50
0
0.1
1
10
10^2
10^3
APPLICATIONS OF TEST TRAFFIC
R 061660-J



TEST TRAFFIC VS
BASE COURSE DENSITY AND CBR
SECTION II
DENSITY IN PER CENT
MOD AASHO
105
100
95
CBR
150
100
50
0
0.1
1
10
10^2
10^3
APPLICATIONS OF TEST TRAFFIC
LEGEND
LANE A
LANE B
LANE C
R 061660-M

PLATE 14



TEST TRAFFIC VS
BASE COURSE DENSITY AND CBR
SECTION III

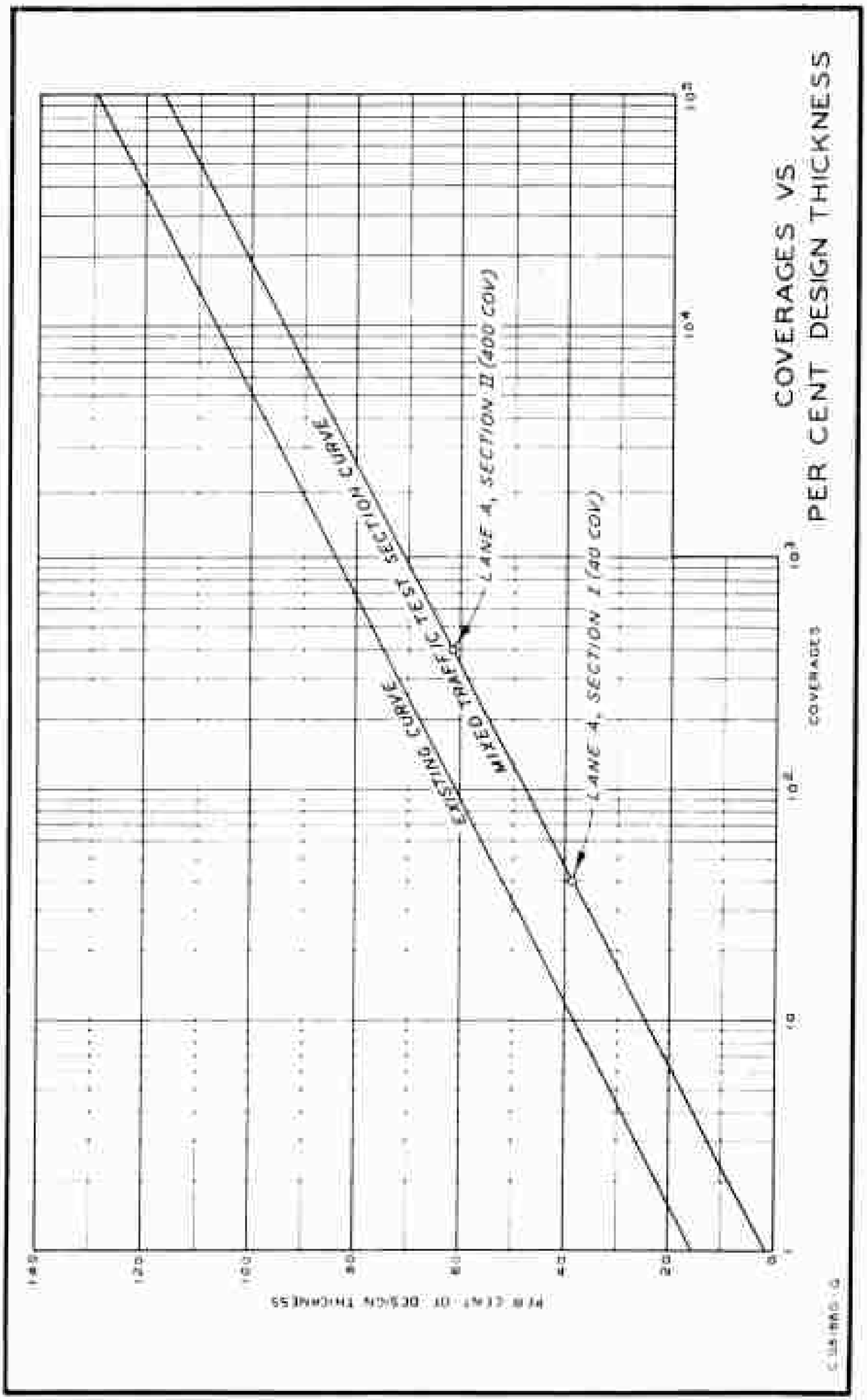

COVERAGES VS
PER CENT DESIGN THICKNESS
EXISTING CURVE
MIXED TRAFFIC TEST SECTION CURVE
LANE 4, SECTION II (400 COV)
LANE 4, SECTION I (40 COV)
COVERAGES
PER CENT OF DESIGN THICKNESS
0
20
40
60
80
100
120
140
1
10
10^2
10^3
10^4
10^5

PLATE 16

U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss. A LIMITED STUDY OF EFFECTS OF MIXED TRAFFIC ON FLEXIBLE PAVEMENTS, by D. N. Brown. January 19[illegible], viii, [illegible] pp - illus - tables. (Technical Report No. 3-587)

Unclassified report

Traffic of [illegible], [illegible], and [illegible]-lb single-wheel load test carts was applied to a test section constructed of a well-graded crushed limestone on a weak clay subgrade to study the effects of mixed traffic on flexible pavements not subject to frost conditions or other conditions requiring special consideration. Deflection, deformation, density, and CBR were measured at specified intervals of test traffic. Test results indicate that the life of a flexible pavement may be materially reduced when as little as 2% of the traffic results from wheel loads two and one-half times larger than the design load; flexible pavements will not necessarily fail immediately when subjected to overloads up to five times larger than the design load; the rate of failure of flexible pavements depends upon the amount and magnitude of this traffic, total thickness of flexible pavement structure, and the condition of the pavement and base; and current criteria for design thickness of the pavement structure are conservative for light loads.

UNCLASSIFIED

1. Bituminous surfacing
2. Pavements

I. Brown, D. N.
II. Waterways Experiment Station, Technical Report No. 3-587

U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss. A LIMITED STUDY OF EFFECTS OF MIXED TRAFFIC ON FLEXIBLE PAVEMENTS, by D. N. Brown. January 19[illegible], viii, [illegible] pp - illus - tables. (Technical Report No. 3-587)

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